NASA Student Launch

2013-2014 CDR

February 28, 2014

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SUMMARY OF CDR REPORT

TEAM SUMMARY

School Name:	University of Louisville
Organization:	*River City Rocketry*
Location:	J.B. Speed School of Engineering 132 Eastern Parkway Louisville, KY 40292
Project Title:	Project Phantom
Mentor Name:	Darryl Hankes
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LAUNCH VEHICLE SUMMARY

The launch vehicle is comprised of two separate stages: a booster stage and a sustainer stage. The two stage rocket will be constructed out of fiberglass and is estimated to weigh in at 50.4 pounds. To deliver the rocket to its predetermined altitudes the rocket will host a Cesaroni M3100-WT motor in its booster stage that will be succeeded by a Cesaroni L1720-WT motor in the launch vehicle's sustainer stage. Four separate recovery systems will be implemented in insure all sections of the rocket land within the kinetic energy guidelines. Altimeter bays have been modeled for the booster, lower, and upper sustainer.

PAYLOAD SUMMARY

The team will focus on designing an efficient two stage rocket featuring a fairing system that will deploy a custom hazard detection system. By adding a booster stage to the rocket will allow the team to fly the hazard detection system to an appropriate altitude in order to carry out its mission's goals. The team has developed a custom rover that will host the hazard detection system. The goal of the rover is designed to be able to interpret the data obtained by the hazard detection system and plot out a safe course to maneuver along once on the ground. A fairing has been designed to safely house the rover. Once the

rocket has reached its designated altitude during descent, the fairing will open and safely deploy the payload.

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	University of Louisville	Milestone	CDR

First Stage (Both Stages Together or Single Stage)		Second Stage (If Applicable)	
Vehicle Properties		**Vehicle Properties**	
Total Length (in)	198 (in)	Total Length (in)	101 (in)
Diameter (in)	6.17 (in)	Diameter (in)	6.17
Gross Lift Off Weight (lb)	74.5 lb	Gross Weight (lb)	30.2
Airframe Material	G12 Fiberglass	Airframe Material	G12 Fiberglass
Fin Material	G10 Fiberglass	Fin Material	G10 Fiberglass
Motor Properties		**Motor Properties**	
Motor Manufacturer(s)	CTI	Motor Manufacturer(s)	CTI
Motor Designation(s)	M3100-WT	Motor Designation(s)	L1720-WT
Max/Average Thrust (lb)	824/701 lbf	Max/Average Thrust (lb)	438/394 lbf
Total Impulse (lbf-sec)	1378	Total Impulse (lbf-sec)	831
Stability Analysis		Ignition Altitude (ft)	2253.10 ft
Center of Pressure (in from nose)	132	Ignition Timing (From 1st Stage Burnout)	+3.0s *
Center of Gravity (in from nose)	119	Igniter Location	Sustainer
Static Stability Margin	2.23	**Stability Analysis**	
Thrust-to-Weight Ratio	9.41	Center of Pressure (in from nose)	93.053
Rail Size (in)	Guide Tower no launch lugs	Center of Gravity (in from nose)	84.36
Rail Length (in)	120 (inches)	Static Stability Margin	1.4
Rail Exit Velocity (ft/s)	42.9 ft/s	Thrust-to-Weight Ratio	8.28
Ascent Analysis		**Ascent Analysis**	
Maximum Velocity (ft/s)	843 ft/s	Maximum Velocity (ft/s)	843 ft/s
Maximum Mach Number	0.75	Maximum Mach Number	0.75
Maximum Acceleration (ft/s^2)	311 ft/s^2	Maximum Acceleration (ft/s)	311 ft/s^2
Target Apogee (1st Stage if Multiple Stages)	3534 ft	Target Apogee (ft)	10000

Recovery System Properties			
Booster Parachute		**Apogee Fairing Parachute**	
Configuration	Round Annular	Configuration	Round Annular
Size	8.9 ft diameter	Size	8.25 ft diameter
Deployment Velocity (ft/s)	0	Deployment Velocity (ft/s)	0
Terminal Velocity (ft/s)	15.583	Terminal Velocity (ft/s)	17.102
Fabric Type	MIL-C-44378 Type IV ripstop nylon	Fabric Type	MIL-C-44378 Type IV ripstop nylon
Shroud Line Material	1/8 inch nylon para-cord	Shroud Line Material	1/8 inch nylon para-cord
Shroud Line Length (in)	133.5	Shroud Line Length (in)	123.75
Thread Type	Nylon Thread	Thread Type	Nylon Thread
Seam Type	French Felled Seam	Seam Type	French Felled Seam
Recovery Harness Type	9/16ths tubular nylon	Recovery Harness Type	9/16ths tubular nylon
Recovery Harness Length (ft)	15 ft	Recovery Harness Length (ft)	25 ft

Harness/Airframe Interface	U-Bolt				Harness/Airframe Interface				
Lower Sustainer Ejection Parachute					**Rover Parachute**				
Configuration	Round Annular				Configuration	Round Annular			
Size	10.104 ft diameter				Size	4.783 ft diameter			
Deployment Velocity (ft/s)	26.11				Deployment Velocity (ft/s)	18.99			
Terminal Velocity (ft/s)	14.646				Terminal Velocity (ft/s)	17.102			
Fabric Type	MIL-C-44378 Type IV ripstop nylon				Fabric Type	MIL-C-44378 Type IV ripstop nylon			
Shroud Line Material	1/8 inch nylon para-cord				Shroud Line Material	1/8 inch nylon para-cord			
Shroud Line Length (in)	151.56				Shroud Line Length (in)	71.745			
Thread Type	Nylon Thread				Thread Type	Nylon Thread			
Seam Type	French Felled Seam				Seam Type	French Felled Seam			
Recovery Harness Type	9/16ths tubular nylon				Recovery Harness Type	9/16ths tubular nylon			
Recovery Harness Length (ft)	15 ft				Recovery Harness Length (ft)	0 ft			
Harness/Airframe Interface	1/4 inch U-Bolt + quick link				Harness/Airframe Interface	Custom parachute cam system descibed in CDR			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4	Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	Booster	Lower Sustainer	Upper Sustainer	rover					
	60	60	60	25					

Milestone Review Flysheet

Institution	University of Louisville

Milestone	CDR

First Stage (or Single Stage)	
Recovery System Properties	
Altimeter(s)/Timer(s) (Make/Model)	MissleWorks RRC3
	MissleWorks RRC3
Transmitters (Model-Frequency-Power)	Garmin ASTRO DC 40
	151,880 MHz
	1W
Black Powder Charge Size Drogue Parachute (grams)	4
	5
Black Powder Charge Size Main Parachute (grams)	3,4
	6,7

Apogee Recovery	
Recovery System Properties	
Altimeter(s)/Timer(s) Make/Model	PerfectFlite Stratologger
	PerfectFlite Stratologger
Locators/Frequencies (Model-Frequency-Power)	Garmin ASTRO DC 40
	151,880 MHz
	1W
Black Powder Charge Size Drogue Parachute (grams)	4
	5
Black Powder Charge Size Main Parachute (grams)	N/A
	N/A

Lower Sustainer Recovery	
Recovery System Properties	
Altimeter(s)/Timer(s) Make/Model	FeatherWeight Raven3
	FeatherWeight Raven3
Locators/Frequencies (Model-Frequency-Power)	Garmin ASTRO DC 40
	151,880 MHz
	1W

Rover Recovery	
Recovery System Properties	
Altimeter(s)/Timer(s) Make/Model	PerfectFlite Stratologger
	PerfectFlite Stratologger
Locators/Frequencies (Model-Frequency-Power)	GPS/GPRS Cape for BeagleBone Black

Black Powder Charge Size Drogue Parachute (grams)	5	Black Powder Charge Size Drogue Parachute (grams)	12.64
	6		17.4
Black Powder Charge Size Main Parachute (grams)	N/A	Black Powder Charge Size Main Parachute (grams)	N/A
	N/A		N/A

Payloads	
Mandatory Payload	Overview
3.1	
Optional Payload 1	Overview
	The launch vehicle will ride on its booster motor until motor burnout. Seconds after burnout a black powder charge will be fired by an onboard StratoLogger to separate the booster stage from the sustainer stage. The onboard Raven altimeter will contorl the ignition of the sustainer's motor soon after separation.
Optional Payload 2	Overview
	The fairing payload was designed around keeping in mind the possiblity of real life applications. Custom machined foam inserts sit inside the fairing and safely house the mandatory payload and the mandatory payload's parachute recovry system. An aluminum cap and shell constrains the fairing shut until a black powder charge in the cap disengages the cap from the shell. The extension springs on the U-bolts on top of the fairing can then pull the fairing open. The mandatory payload safely slips out of the fairing.

Test Plans, Status, and Results	
Ejection Charge Tests	An assembled rocket be ground tested by placing the desired black powder chage in the proposed areas. The ejection charge will be remotely activated to determine how well the ejection charge worked.
Sub-scale Test Flights	Subscale testing will be utilized to test dual staging procedures. The team will also test the vehicle's stability through subscale launches. A subscale version of the fairing payload will be devloped and flown on the subscale launch vehicle in order to test out the functionality of the system.
Full-scale Test Flights	The full scale will test both mandatory and optional payloads.

Additional Comments
* This time is to motor thrust, to accomplish this time when motors are received we will staticly test one and determine when to ignite the motor to achieve thrust at the 3 second time that was stated.

CHANGES MADE SINCE PDR

CHANGES TO VEHICLE CRITERIA

Since the PDR, the launch vehicle has undergone 3 primary changes.

1. Visually, the most notable change since the PDR has been the rocket's change in height. Due to an underestimation in the packing size of the recovery systems, the lengths of the various sections of airframe had to be increased. This brought about a change in total height of the rocket to 198 inches.
2. Due to the aforementioned design change since PDR the team had to change out the motor selection for both the booster and sustainer. Previously, the rocket was slated to be powered by a Cesaroni L1350-CS motor in the booster, and a Cesaroni L910-CS in the sustainer. Due to the increased weight of the rocket, the booster will now host a Cesaroni M3100-WT motor while the sustainer will be powered by a Cesaroni L1720-WT motor.
3. After subscale testing the team noticed that the coupling method for the rocket's staging was inefficient. The subscale had a section of coupler tubing which was permanently epoxied at the base of the sustainer with a 3 inch offset. The booster section's upper airframe was joined at this section. It was noted that the sustainer's motor exhaust temperatures were negatively effecting the resin within the overhanging coupler tubing. With the fear of failure in mind, the team now has the coupling section of tubing permanently fixed to the upper portion of the booster stage. There is no airframe overhanging the motor anymore.
4. The altimeter sleds and bays have been redesigned to fit the new separation design, a test parachute was created and tested for drag characteristics, and recovery logic has been documented,

CHANGES TO PAYLOAD CRITERIA

1. The fairing deployment system requires a custom pyro cap to be ejected from the fairing. In order to make our launch vehicle's system fully redundant, the team has designed the pyro cap to have two separate black powder chambers, with two electronic matches routing into either chamber.
2. Similar to the above change, the team has added a second altimeter housing to the fairing system. This altimeter housing will be in control of the second black powder chamber added to the pyro cap.

CHANGES MADE TO PROJECT PLAN

Currently there have been no notable changes to the project plan. The team has had minor issues with a couple purchasing orders, but they do not plan on this having an effect on the overall timeline laid out in the project plan.

VEHICLE CRITERIA

DESIGN AND VERIFICATION OF LAUNCH VEHICLE

Design Overview

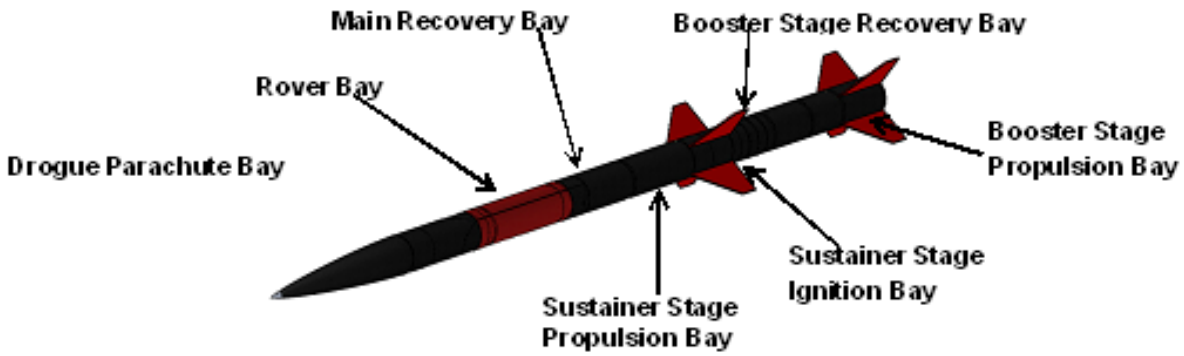

Figure 1: Vehicle bay layout

This year, the major vehicular design is being based upon two central missions; the first being using multiple motors in an inline staged format, and the second being a fairing system designed to release an autonomous rover to complete the desired mission. The inline staging requires a look at the efficiency of all systems, including, but not limited to the following: overall mass of components, component material choices, reducing unused bay space, and using designs which improve precision during manufacturing of individual components and assembly of the overall vehicle. Due to the demands of the inline stage format, recovery systems are at the forefront of the sub systems. Figure 2 illustrates the vehicle recovery flight path.

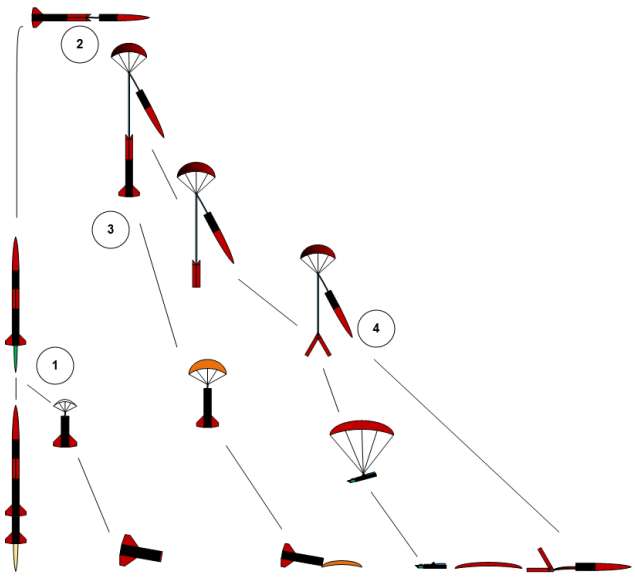

Figure 2: Vehicle recovery flight path

As shown in figure 2, the vehicle descends in four separate pieces, which will require precision and accuracy when packing each system.

Applicable Formulations

It is appropriate to outline basic equations used in vehicle calculations. Three core values must be calculated to assess the stability and success of the rocket: peak altitude, center of gravity, and center of pressure. The peak altitude is found through a precise sequence of equations. The average mass is first calculated using

$$m_a = m_r + m_e - \frac{m_p}{2} \quad (1)$$

where m_r is the rocket mass, m_e is the motor mass, and m_p is the propellant mass. The aerodynamic drag coefficient (kg/m) is then computed by

$$k = \frac{1}{2}\rho C_D A \quad (2)$$

where ρ is the air density (1.22 kg/m^3), C_D is the drag coefficient, and A is the rocket cross-sectional area (m^2). Equations 1 and 2 are utilized to calculate the burnout velocity coefficient (m/s) using

$$q_1 = \sqrt{\frac{T - m_a g}{k}} \quad (3)$$

where T is the motor thrust , and g is the gravitational constant (9.81 m/s^2). Equations 1, 2, and 3 are then used to compute the burnout velocity decay coefficient (1/s) using

$$x_1 = \frac{2kq_1}{m_a} \quad (4)$$

Equations 3 and 4 are used to calculate the burnout velocity (m/s) using

$$v_1 = q_1 \frac{1 - e^{-x_1 t}}{1 + e^{-x_1 t}} \quad (5)$$

where t is motor burnout time (s). The altitude at burnout can then be computed by

$$y_1 = \frac{-m_a}{2k} \ln\left(\frac{T - m_a g - k v_1^2}{T - m_a g}\right) \quad (6)$$

Once the burnout altitude is calculated, the coasting distance must be determined beginning with the calculation of the coasting mass using

$$m_c = m_r + m_e - m_p \quad (7)$$

The coasting mass replaces the average mass in equations 3 and 4 resulting in equations 8 and 9 for the coasting velocity coefficient and coasting velocity decay coefficient, respectively:

$$q_c = \sqrt{\frac{T - m_c g}{k}} \quad (8)$$

$$x_c = \frac{2kq_c}{m_c} \tag{9}$$

Equations 8 and 9 can then be utilized to determine the coasting velocity (m/s) using

$$v_c = q_c \frac{1-e^{-x_c t}}{1+e^{-x_c t}} \tag{10}$$

The coasting distance can then be computed using

$$y_c = \frac{m_c}{2k} \ln\left(\frac{m_c g + kv^2}{m_c g}\right) \tag{11}$$

The peak altitude is then determined using

$$PA = y_1 + y_c \tag{12}$$

The center of gravity location is calculated using

$$cg = \frac{d_n w_n + d_r w_r + d_b w_b + d_e w_e + d_f w_f}{W} \tag{13}$$

where W is the total weight, d is the distance between the denoted rocket section center of gravity (nose, rocket, body, engine, and fins, respectively) and the aft end.

The center of pressure measured from the nose tip is calculated using

$$X = \frac{(C_N)_N X_N + (C_N)_F X_F}{(C_N)_N + (C_N)_F} \tag{14}$$

where C_{NN} is the nose cone center of pressure coefficient (2 for conical nose cones), X_N is the computed by

$$X_N = \frac{2}{3} L_N \tag{15}$$

where L_N is the nose cone length. C_{NF} in equation 14 is the fin center of pressure coefficient calculated using

$$(C_N)_F = \left[1 + \frac{R}{S+R}\right] \left[\frac{4N\left(\frac{S}{d}\right)^2}{1+\sqrt{1+\left(\frac{2L_f}{C_R+C_T}\right)^2}}\right] \tag{16}$$

where R is the radius of the body at the aft end , S is the fin semispan , N is the number of fins, L_F is the length of the fin mid-chord line, C_R is the fin root chord length, and C_T is the fin tip chord length . X_F in equation 14 is calculated using

$$X_F = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R+C_T)}\right] \tag{17}$$

where X_B is the distance from the nose tip to the fin root chord leading edge, X_R is the distance between the fin root leading edge and the fin tip leading edge measured parallel

to body. Equations 14 through 17 are also known as the Barrowman Equations (The Theoretical Prediction of the Center of Pressure, 1966).

1. *Vehicle Requirements*

1.1. The target altitude for our rocket system is 10,000 feet above ground level. This will be achieved by calibrating the mass ballast system to counter the booster and sustainer rocket motors.

1.2. Our rocket will be utilizing two RRC3 altimeters, two PerfectFlite Stratologgers for use in the nosecone to detect the apogee height, and four Featherweight Ravens that will act in parallel to measure and report the altitude to the rest of our systems. We will be designating one of the Stratologgers as the altimeter for the official competition altitude.

1.2.1. One of the PerfectFlite Stratologgers will be marked as the official competition altimeter.

1.3. The rocket's flight systems are able to be re-used; battery systems and the motors can be removed and replaced with new units after each flight.

1.4. Most of the assembly will be completed before arrival at the launch site. The only remaining tasks to complete at the site will be the initialization of the electronic systems, assembly of the motors, assembly of the AV bays by way of installing rivets, and attaching the motor retainers.

1.5. Provided that new batteries are installed in each slot on the day of the launch, the rocket will be able to last ten hours on the launch pad in a ready-to-launch state without change.

1.6. The vehicle will utilize a standard commercial igniter, which will be chosen following the assembly of the full scale rocket.

1.7. As stated before, the rocket will use a standard commercial igniter, which will be capable of using the standard 12V direct current source.

1.8. The motors the team has selected to use in the competition will be a Cesaroni L910 for the sustainer and L1350 for the booster. This choice of Cesaroni as the supplier was based upon team familiarity with motors of this type. Cesaroni motors are known for their ease of use, reliability, and performance

1.9. There are no pressure vessels included in the design of our rocket for this competition.

1.10. The full scale test flight will take place at the event "Thunderstruck", which will take place in the first week in April. The final system's functionality will be verified in the future at this event following the manufacturing and assembly of the full-scale rocket.

During the construction of the rocket, workmanship must be taken as seriously as the initial design. To ensure maximum precision, the team will be making many components utilizing CNC machining technologies.

Several of the components will also be made using standard machining processes. Even without computerization, accuracy within ±0.001 is very feasible.

Through accurate machining, careful assembly, and thorough checks, the team will be able to increase chances of mission success by eliminating potential problems due to poor workmanship.

In addition to the testing discussed in the PDR, additional motor testing will be conducted on both types of motors for the sustainer and the booster. These tests will take place when the motors arrive from Wildman Rocketry. Separation events, caused by black powder charges, will be tested following the construction of the system.

The full-scale manufacturing and assembly will begin following the delivery of parts in the next two weeks (planned delivery date: March 14th, 2014). The full scale will take approximately three weeks and will be assembled before the full scale test flight at "Thunderstruck", which will take place during the first week of April.

Nose Cone Design

The current design for the nose cone was researched and designed to provide the optimal degree of lift versus drag to meet our target speed and to accomplish the tasks set forth by the competition. There are several designs from which we could have chosen, including the tangent ogive, the secant ogive, the parabolic, and the Von Karman designs.

The initial type of cone that we selected was the tangent ogive, as was used in the previous year's design. The tangent ogive melds smoothly with the rest of the body, provided that the equation is utilized properly.

Through our research, we determined that the Von Karman design would be the best suited to our goal (reaching a speed of about 0.8 Mach). Figure 3 below shows degrees of effectiveness for various nose cone designs with respect to varying Mach numbers.

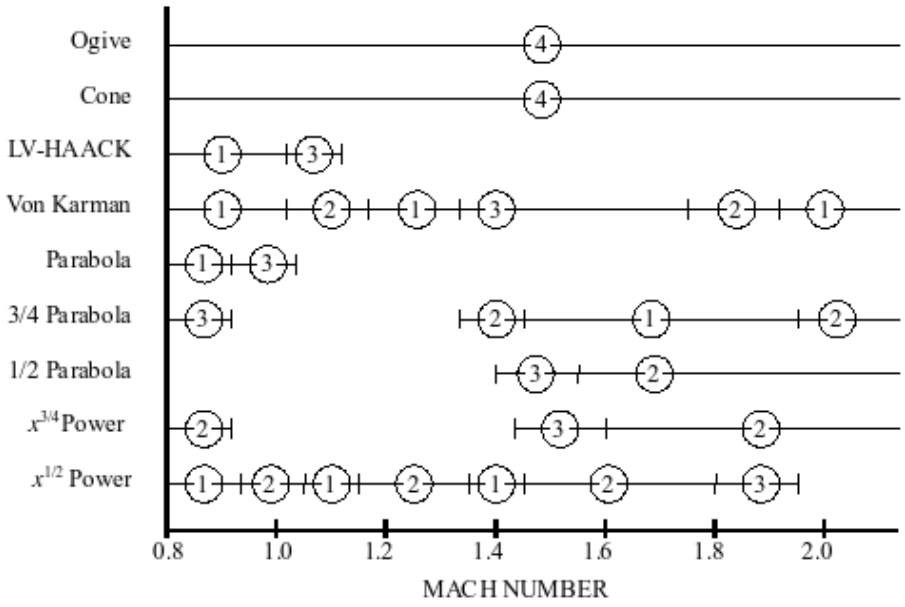

Figure 3: Nose Cone Effectiveness Comparison

As seen from the graph, the Von Karman is ranked “1” for the desired Mach range in which the rocket will fly. In addition, it also has a relatively wide range ranked “1” which gives us a bit of leeway in case our speed varies.

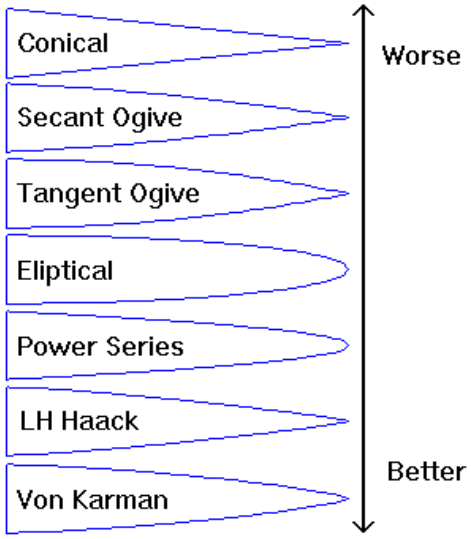

Figure 4: Nose Cone Effectiveness Comparison #2

Figure 3.2 relates a generalized version of the first, indicating that the LH Haack and the Von Karman are the two most effective designs for the flight.

The equations used to generate the Von Karman (LD-Haack) type cone in our SolidWorks renderings are shown by Equations 18 and 19.

$$y = \frac{R}{\sqrt{\pi}}\sqrt{\theta - \frac{\sin(2\theta)}{2} + C sin^3\theta} \quad (18)$$

$$C = 0 \; for \; LD - Haack \quad (19)$$

The components chosen are shown in the exploded view of the nose cone bay below. The cone itself is of the Von Karman design, while the specialized parts (washers, bolts, and U-bolt) will be supplied by a hardware manufacturer. Additionally, the nose cone will house a GPS sled to track the section upon separation from the main vehicle. The recovery portion of the nose cone and fairing section will be described later.

Figure 5: Von Karman Nose Cone.

As mentioned before, we chose to use the Von Karman design because we discovered that it provided the optimal ratio of lift versus drag for our intended speed. The tip of the cone, made out of machined aluminum, ensures a perfect point and more rigid surface for decreased deformation during landing. At the rear of the cone is an elongated shoulder which will allow us to ensure a snug fit with the rest of the rocket's body.

This particular piece will be purchased through Rocketry Warehouse and will be according to the specifications specified. It will be a six inch diameter filament wound fiberglass nose cone with a caliber ratio of 5:1.

The nose cone system, being the leading edge of the rocket, is integral to the overall performance of the rocket. Due to the varying materials in the tip, the rocket will be able to cut more smoothly through the air than if it were made of the material composing the rest of the shell. Without the bulkhead residing in the base of the shell, nose cone and fairing system would lack a recovery device and would therefore lack another essential stabilization. The rocket nose cone, being a static component of the overall system, is a foundation piece. It can change, but the factors that would initiate a change are few and are relatively isolated to the mechanical aspects of the overall design.

Name of Part	Design / Type	Size/Ratio	Materials
Nose Cone (x1)	Von Karman	6in. diameter / 5:1	Filament-wound Fiberglass + ABS Plastic tip
Centering Ring (x1)	N/A.	6in. outer diameter 5in. inner diameter 0.5in. thick	Balsa Wood
Wooden Bulkhead (x1)	N/A.	5in. diameter 0.5in. thick	Balsa Wood
Bulkhead (x1)	N/A.	6in. diameter 0.14in. thick	G10 Fiberglass
Threaded Rod (x2)	N/A.	0.25in. diameter 3in. long	Aluminum 6061-T6
Threaded Rod (x2)	N/A.	0.25in. diameter 10in. long	Aluminum 6061-T6
U-Bolt (x1)	Extended Length U-Bolt	3/8” – 16 Thread 2 7/16” Width (Inside Edges)	Stainless Steel
Washers (x4)	General Purpose Washer	3/8” Screw Size	Stainless Steel
Nuts (x4)	Standard Hex Nut	3/8” – 16	Stainless Steel

Table 1: Material specifications for nose cone design

Sustainer Stage Ignition Bay

The sustainer stage ignition bay will serve three purposes:

1. Connect the booster stage to sustainer stage during booster burn phase
2. House black powder charges for booster stage separation
3. House and protect the ignition system for the sustainer stage

The bay will be composed of a 6.0” fiberglass body tube measuring 6.0” in length. The read centering ring will be placed 3.5” from the rear of the sustainer. This will allow the forward coupler of the booster stage to seamlessly couple with the sustainer stage, as seen in the figure below.

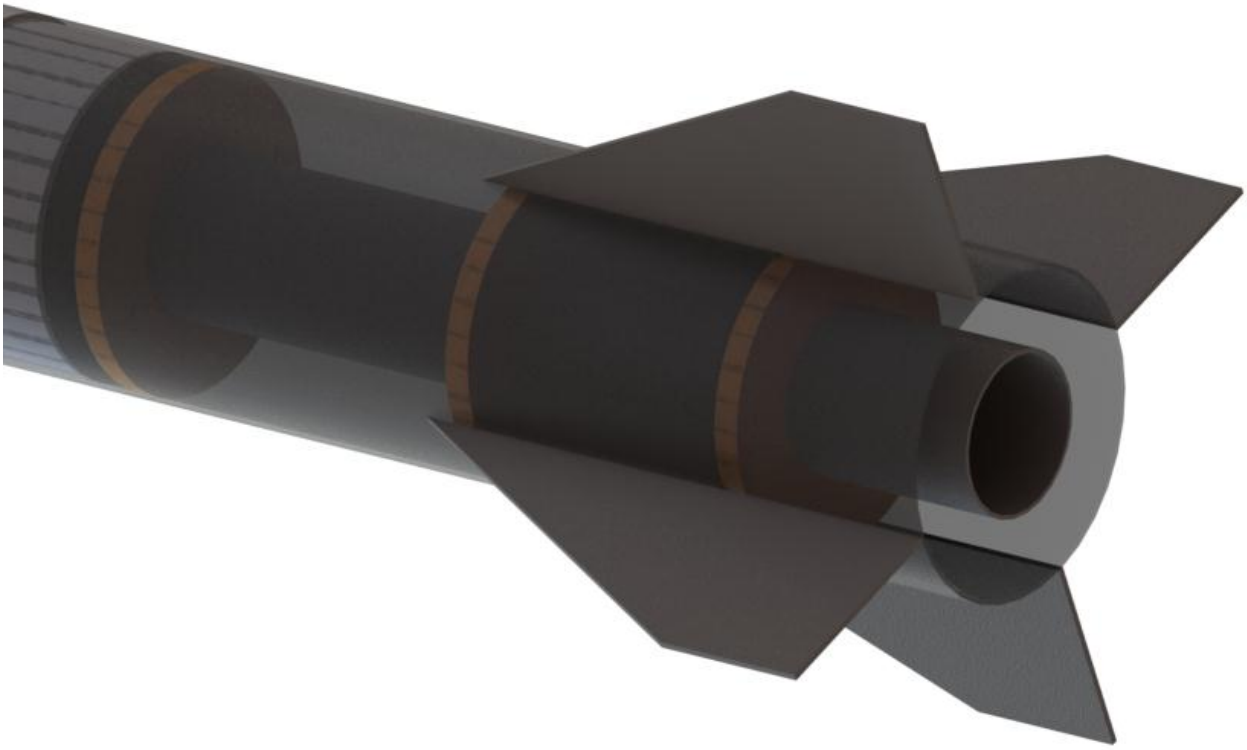

Figure 6: Sustainer stage propulsion bay connection.

Located inside of the first centering ring of the sustainer stage propulsion bay will be the ignition control system for the sustainer stage. This system will be run using a Featherweight Raven altimeter. The system will have two outputs, the first being for the ignition of the black powder for sustainer stage separation. The second output will be for the ignition of the booster stage following the burn out and separation of the booster stage.

The two outputs will be programmed using the Featherweight interface. The planned programming is given in the next section.

To promote safety, calculations have been done to find the range of altitudes the rocket must reach for the ignition of the sustainer stage to take place. This range takes into account a maximum offset of 10 degrees from vertical. Additionally, a mechanical rolling switch will be positioned inside of the sustainer stage ignition bay to detect stage separation. If stage separation does not occur and/or the altitude conditions are not met, sustainer stage ignition will be aborted and the vehicle will continue through the rest of the programmed mission.

Booster Stage

The booster stage will serve a single purpose:

1. Boost the sustainer to an altitude of 3,699 feet where the sustainer's motor will then ignite to propel the second stage to the target altitude of 10,000 feet.

The booster stage is comprised of a 6.0 inch diameter outer tube comprised of G-12 fiberglass. At the top of the stage, near the coupler and the sustainer ignition bay, the RRC3 altimeter pair that governs the actions of the booster stage reside on a sled suspended between two threaded aluminum rods placed at 180 degrees from each other. The logic for these two altimeters is listed in Figure 6 below.

Booster Recovery

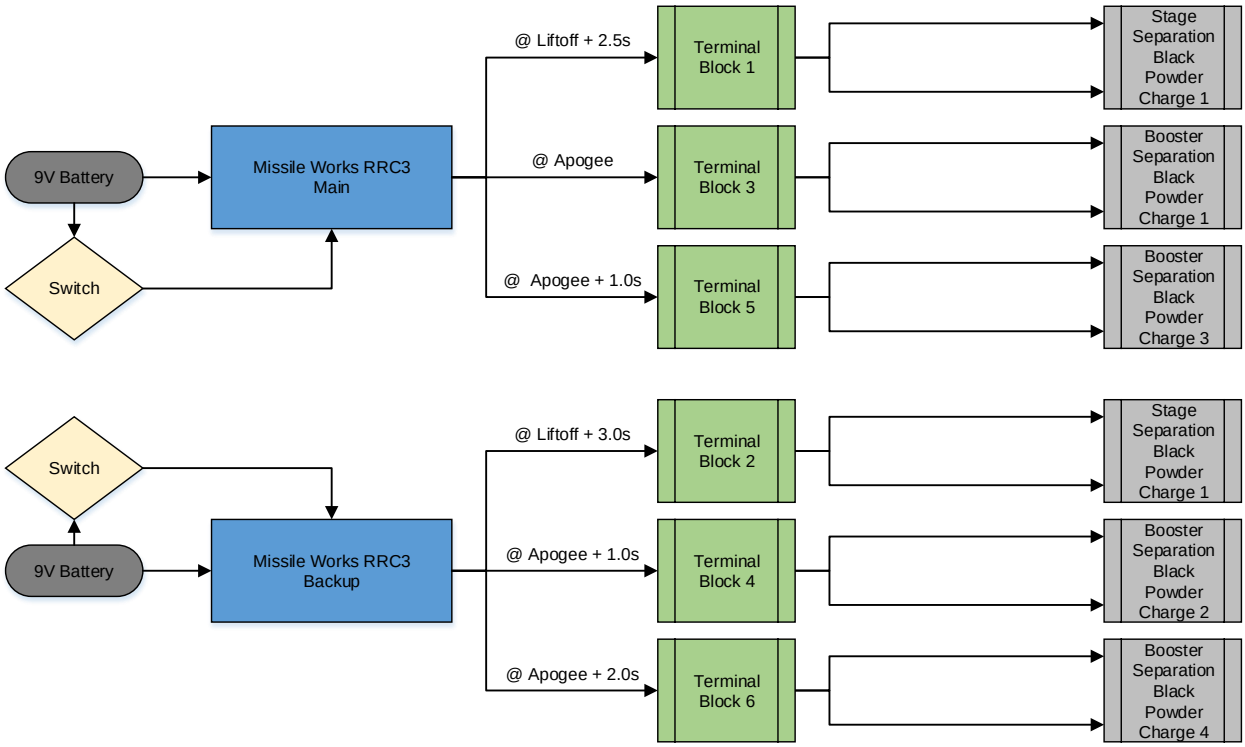

Figure *7*: Booster recovery logic.

The booster will be the first section to be recovered, at motor burnout two MissleWorks RRC3's will be used to separate the booster from the sustainer. These altimeters were chosen for being both able to separate the booster and provide redundant recovery events at apogee at half of the price of the Raven. There are two black powder charges at apogee + 1.0 seconds, this is due to the combination of one altimeter being in backup mode and the other being in apogee only mode.

2nd Stage Motor Ignition

Using OpenRocket and taking an iterative approach with the new larger vehicle it was determined that to achieve the highest altitude that the 2nd stage motor will have to provide thrust 3.0 seconds after burnout. In the following flowchart it shows the ejection

charge as being 3.0 and 3.5 seconds, those values are placeholders until we are able to statically test the motor. The motor will be tested on a static thrust stand and the time taken from sending the ignition signal until the motor produces thrust will be documented and then subtracted from the 3.0 second delay. Two igniters will be used with one from each Raven for redundancy.

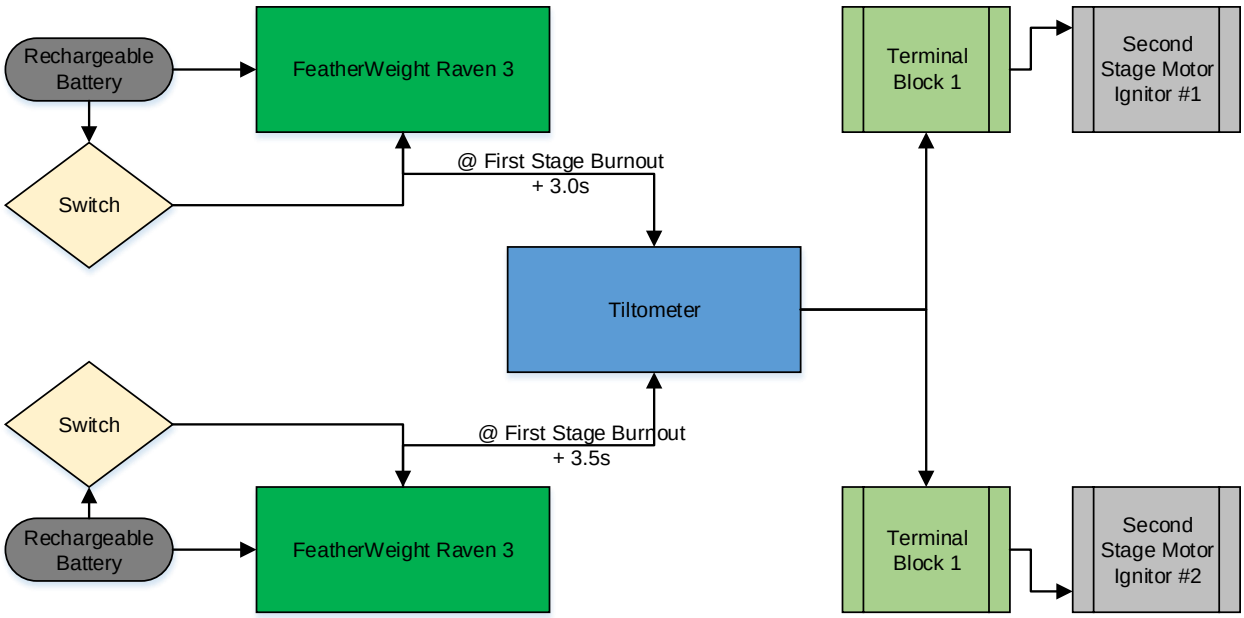

Figure 8: 2nd Stage ignition logic.

Apogee Event

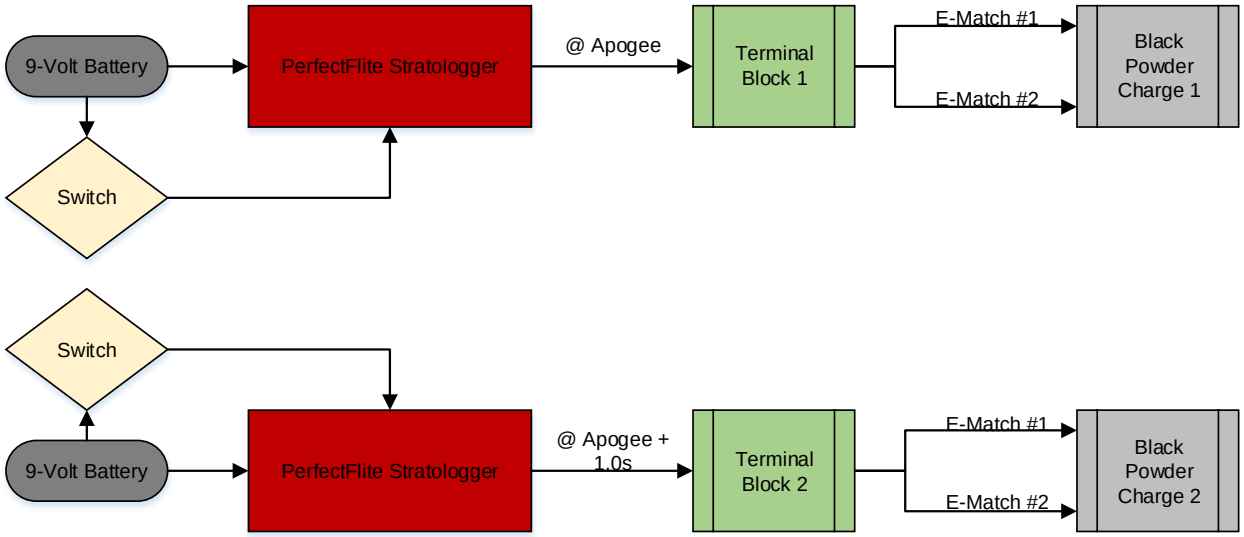

Figure 9: Apogee recovery logic.

The apogee event uses two StratoLogger's that deploy at apogee and apogee + 1.0 seconds. This is a standard dual deployment for high powered rocketry.

Lower Sustainer Ejection

The lower sustainer will be ejected at 7500 ft. and will be under parachute when ejected. The same Ravens that powered the motor ignition will power the black powder charges to separate the lower sustainer from the fairing payload.

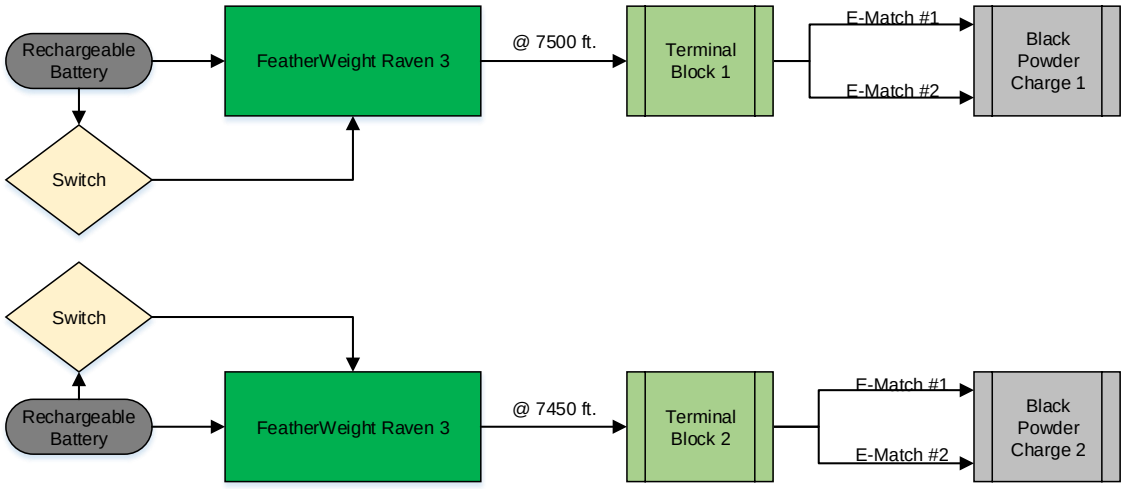

Figure 10: Lower sustainer recovery logic.

Fins

The fins used on the rocket's booster and sustainer are constructed out of G-10 fiberglass and have the dimensions listed in the table below.

	Booster Fin Set	Sustainer Fin Set
Number of Fins	4	4
Fin Rotation (degrees)	0	0
Fin Cant (degrees)	0	0
Root Chord (in.)	10	11
Tip Chord (in.)	2	3
Height (in.)	4	4
Sweep Length (in.)	8.95	8.94
Sweep Angle (degrees)	63.4	63.43
Thickness (in.)	0.125	0.125

Table 2. Fin dimensions.

G-10 fiberglass is well-known for its use in model rocketry and is renowned for its strength and high factory of safety when under stress. Below is a rendered image of one of the booster fins.

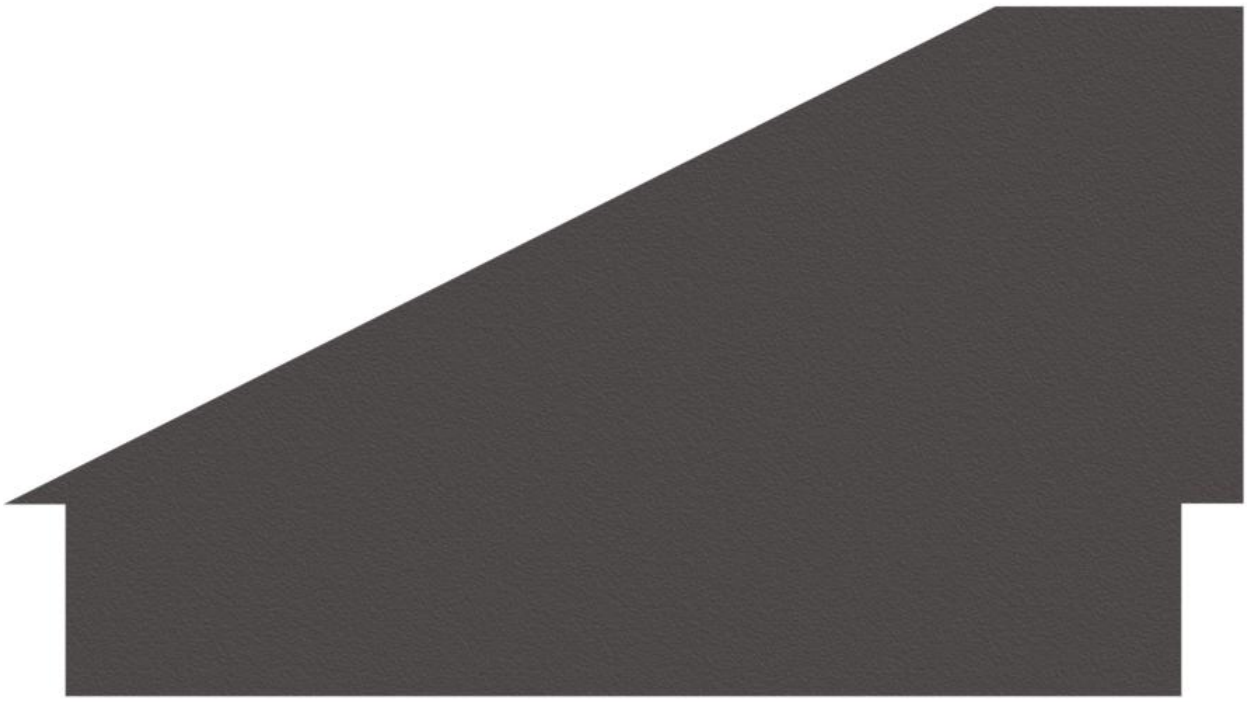

Figure 11. Booster fin.

The fin has a tab that is inserted into the body of each stage, which will be epoxied (using Proline epoxy) to the inner tube, centering rings, and the outer airframe to ensure complete stability and adhesion to the rocket. The overhang on either end of the tab will allow the epoxy to bind to a larger surface area than if the tabs extended all the way along the root chord.

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There are six wooden bulkheads in areas that bear little to no stress and therefore do not need high strength, heavy-weight materials. Six G10 fiberglass bulkheads supply high strength materials in stress bearing locations and one 6061-T6 aluminum bulkhead provides the strength needed to withstand the stress input in that area.

Several aluminum threaded rods are included in the design. These allow electronics to be mounted between the bulkheads.

Permanent assemblies (ie, fins, inner tubes, centering rings, and bulkheads) are assembled using Proline epoxy and J.B. Weld. This ensures stability and permanent adhesion between parts. The AV bays are riveted together to allow the bays to be removable after flight.

The first and second stages, the booster and sustainer respectively, are attached using two 4-40 shear pins located 180 degrees from each other. These pins will release when the black powder charges ignite, allowing for stage separation and clearance from the booster stage.

The motors will be inserted into a 2.953 inch inner tube, which is epoxied to the centering rings and the fins. The fins and the centering rings are in turn epoxied to the outer airframe, thus ensuring a snug, permanent fit. In order to prevent the loss of the motor during flight, a 75 millimeter Aeropack motor retention ring will be attached to the bottom of the sustainer and booster's motors. The retention ring on the booster will have a flange while the sustainer will not. The 75mm retention ring is shown below.

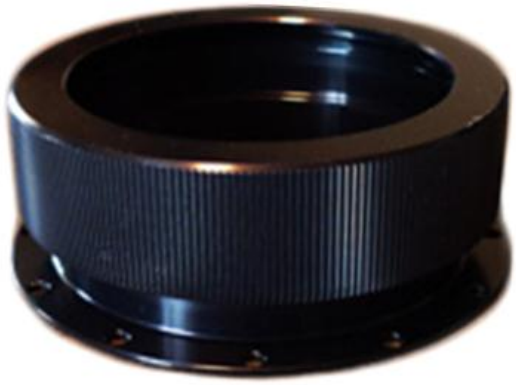


Figure 12. Aeropack 75mm motor retention ring.

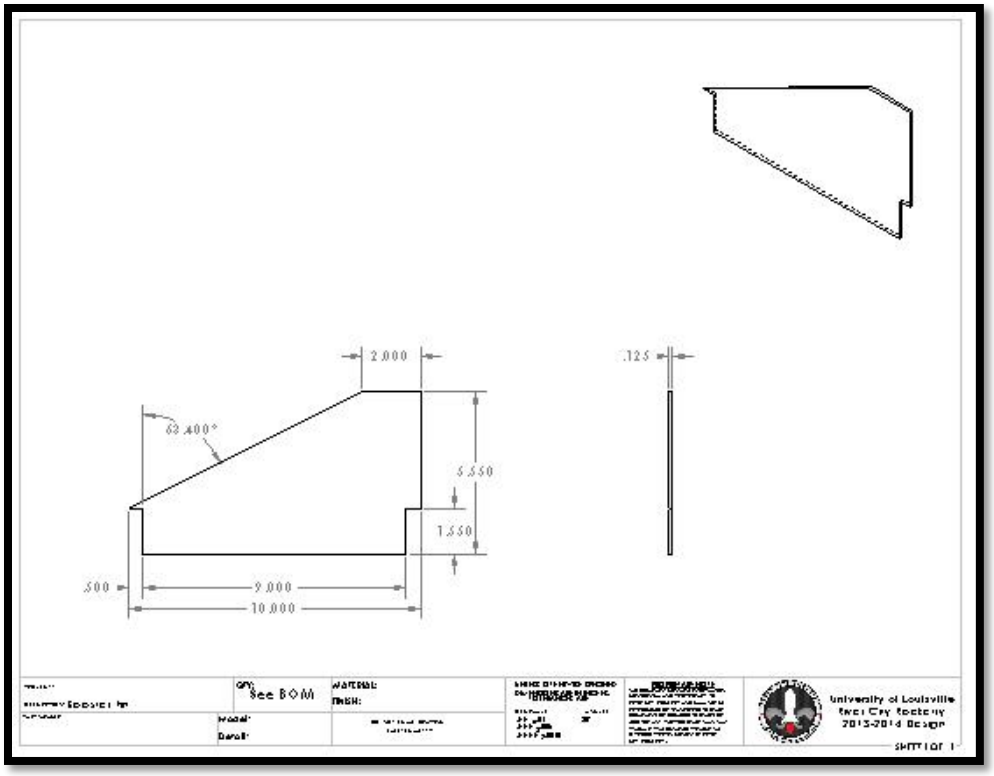


Figure 13. Booster Fin.

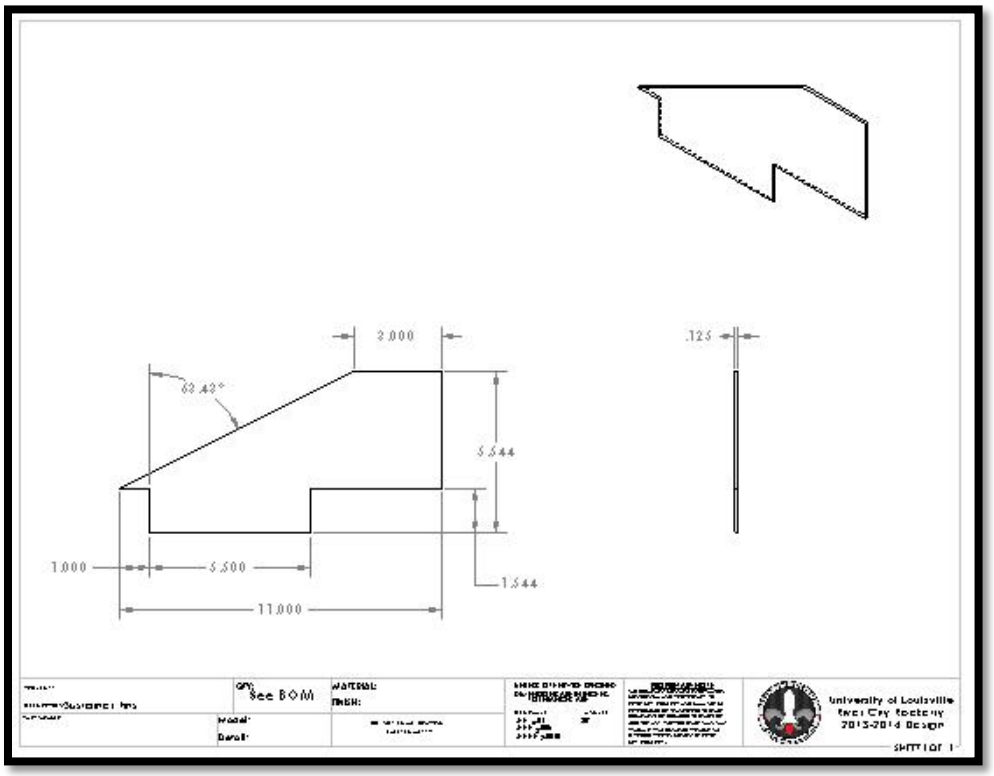


Figure 14. Sustainer Fin.

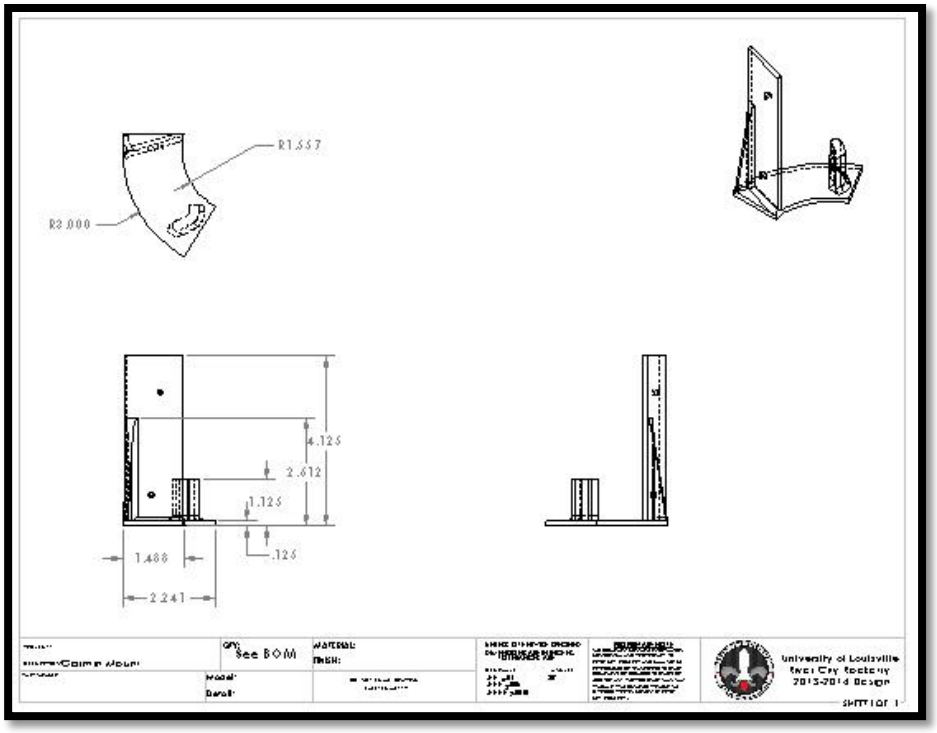


Figure 15. Garmin Mount

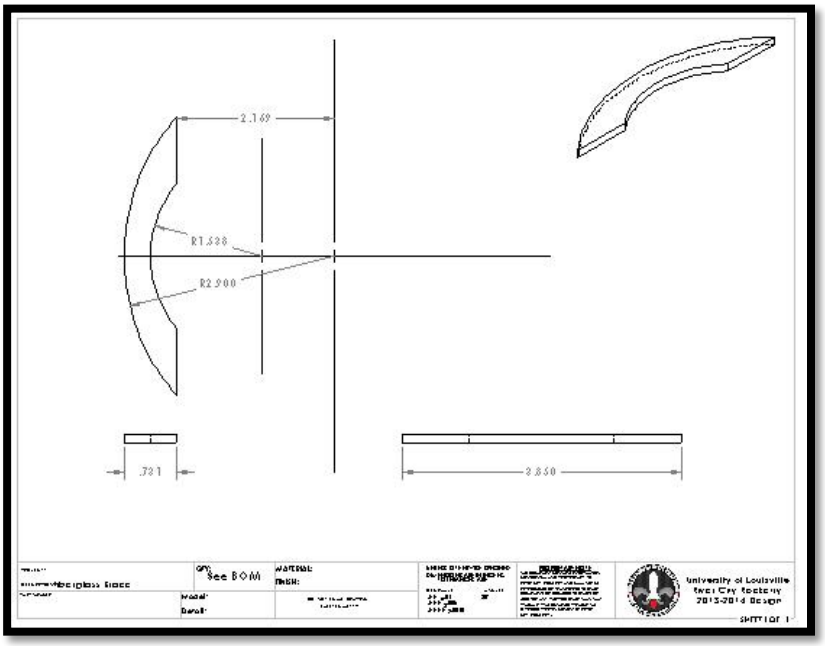


Figure 16. Fiberglass Brace

Mass Statement

The current mass of the rocket with motor is 72.5 lbs. This number is our target to hit, whether by removing or adding additional weight. The amount of weight added through

mass compensation will never exceed 10% of the rocket's total weight. A weighted ballast system will be integrated to maintain the stability margin. Factoring in the added weight due to epoxy, the rocket has a mass tolerance of four pounds before it drops below the target altitude of 10,000 feet.

Our predictions have the rocket weighing in at this target with every component simulated. Through accurately weighing each component, and overriding mass estimates in OpenRocket simulation software, we have high confidence in our predictions.

SUBSCALE FLIGHT RESULTS

The subscale build and flight allowed the team to gather an enormous amount of data and hands on knowledge of complex rocketry design. The subscale was where the team first discovered it had underestimated the rocket's recovery system's sizes. The design for the subscale originally called out for a 5 foot and 6 inch rocket. After the recovery system's sizes were re-evaluated and corrected the team's subscale was just shy of 7 feet and 9 inches. The team flew the rocket twice, and noticed a few key design flaws that would transfer over into a redesign into the full-scale.

Figure 17. View of the staging coupler overhang.

The primary design challenge for the team was to determine how to properly couple the two stages together. The team decided to have a piece of coupler tubing epoxied into the bottom of the sustainer's lower airframe. This coupler tubing had a 3 inch overhang below the sustainer in order to allow the booster's upper airframe to securely couple with the sustainer. In order for the coupler tubing to be properly inserted and not interfere with the fins, precisions cut fin slots were cut into the tubing.

Figure 18. Sustainer stage motor tube assembly with centering rings and staging coupler.

With this design finalized, the team was pleased with the form and fit of the two stage launch vehicle.

The first flight of the subscale was more eventful than the team prepared for. After the electronics were wired in and double checked the rocket stages were coupled together. In order to make sure the coupling of the sections were snug, a small strip of duct tape was applied on either side of the stage coupler. All systems were checked again, and the rocket was placed on the launch rail, ready for launch.

Figure 19. First launch of the subscale.

The booster motor fired, and lifted the rocket to its estimated altitude. The Raven altimeters in the booster altimeter bay successfully ignited the sustainer motor. Almost immediately after sustainer motor ignition, a loud explosion occurred and the sustainer's motor went out. The booster was rapidly jettisoned back down towards the ground. The sustainer continued to arc over and deployed it's drogue parachute at apogee. Since the rocket never made it above the altitude where the main chute deployment was programmed into the StratoLogger the rocket immediately fired the black powder charges for the main following drogue deployment.

After further analysis of the rocket and all of its components the team saw that all electric matches were fired. Due to the violent deceleration of the booster section, the altimeter bay at the top of the booster was forced down into the lower airframe. Even though the black powder charges for the booster main parachute fired, the coupler was unable to be jettisoned due to the deformation of the accident.

Figure 20. Damaged components from the booster stage's altimeter bay.

The team determined that the addition of the duct tape around the coupler tubing created too much friction between the staging couplings. It was determined that when the sustainer motor ignited, the pressure created in the coupling section between the two stages was large enough to cause the violent explosion. Once the two stages separated the dramatic change in pressure between the inside of the coupling and the outside pressure caused a rapid evacuation of the air within the motor and coupling section. The team determined that this quick release of air sucked out any and all burning particles of propellant that would have continued to light the motor.

The team had to go back and rebuild the booster airframe and altimeter bay in order to make the rocket flight ready. The team discussed different staging strategies with its mentor and determined that it is more desirable to have a more loose fit, than a more snug fit. For the second flight, the team made sure all connections were correct again with the electronics and then prepared to couple the two stages. This time the team sanded the coupler tubing to allow for a smooth and easy coupling. Once together, a small piece of masking tape was applied across the mating section of the two stages. Two small slits were cut into both sides of the tape so as to allow for easy tearing during stage separation.

Figure 21. Second launch of the subscale.

The rocket was set on the launch rail, the electronics were turned on, and the launch vehicle was ready for launch. After booster burnout, the sustainer stage ignited and successfully separated from the booster. The sustainer climbed to its estimated altitude while the booster's main parachute was deployed at its apogee. The sustainer continued to climb to its apogee and successfully deployed both its drogue and main parachutes and their appropriate altitudes. Both booster and sustainer sections landed within 200 yards of the launch pad.

RECOVERY SUBSYSTEM

Overview

The purpose of any vehicle is to deliver a payload so that the payloads mission can be completed successfully. Because this vehicle has multiple payloads the requirements for each payload were factored in to determine the recovery method.

Payload	Requirements the recovery system must satisfy
Hazard Detection	Be able to land and perform surface maneuvers.
Stage Separation	Land independently of the launch vehicle.
Fairing	Be able to eject a payload during descent.

Table 3. Payload specific recovery requirements.

For the hazard detection payload to be able to perform surface maneuvers it must either be able to leave the vehicle after landing or be ejected during descent, the fairing must be able to eject a payload during descent. To reduce complexity it was decided to merge these two requirements and recover each rocket section independently under its own parachute. The sections that will be recovered will be the booster section, the lower sustainer, the hazard detection payload, and the nose cone with the fairing tethered to the nose cone.

Recovery Requirements

The recovery system must meet the following requirements set forth by the Statement of Work (SOW) and those set forth by the team, shown below, to be considered a success.

1. The parachute system(s) shall be designed and manufactured by the team. Commercially available parachute systems shall not be used on the vehicle.
2. At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lb_f,
3. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.
4. The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.
5. Each altimeter shall be armed by a dedicated arming switch which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
6. Each arming switch shall be capable of being locked in the ON position for launch.
7. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.

8. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.
9. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch till landing).

The recovery system must meet the following requirements which have been set forth by the team.

10. The recovery system shall create an opening such that the recovery harness will not fail.
11. At landing the hazard detection payload at a landing kinetic energy less than 25 ft-lb_f.
12. Every recovery event will feature redundant ejection charges.
13. The recovery system shall not create opening shock high enough that the recovery harness suffers damage.
14. All suspension lines are to be removable in the event of an incident and they need replaced.

Parachute Selection

Parachute are broken down into the following types: solid textile, slotted, and rotating (Knacke 5-3). With four parachutes being used during descent and all of them being in the air simultaneously the chances of a midair collision are much higher than one active parachute as seen in a dual deployment scheme. By keeping all parachutes the same type the flight path will be more similar than if each was different, for this reason it was deemed that all parachutes will have the same geometry.

Geometry

The parachute geometry was selected to minimize the total mass of all parachutes. To accomplish this the geometry with the highest drag coefficient and minimum area was chosen. Table 4 shows drag coefficient ranges vs. parachute geometry, the drag coefficient is based on total area including the vent hole and all openings (Knacke 5-3).

Parachute Geometry	Drag Coefficient Range	
	Lower	Upper
Annular	0.85	0.95
Triconical	0.8	0.96
Extended Skirt (10% Flat)	0.78	0.9
Flat Circular	0.75	0.8
Conical	0.75	0.9
Extended Skirt (14.3% Flat)	0.75	0.9
Ringsail	0.75	0.85
Biconical	0.7	0.92
Hemishperical	0.62	0.77

Cross	0.6	0.85
Ringslot	0.56	0.65
Disc - Gap - Band	0.52	0.58
Conical Ribbon	0.5	0.55
Flat Ribbon	0.45	0.5
Guide Surface (Ribbless)	0.3	0.34
Ribbon (Hemisflo)	0.3	0.46
Guide Surface (Ribbed)	0.28	0.42

Table 4. Drag coefficient range vs. parachute geometry.

The triconical had the highest upper drag coefficient and the annular had the highest lower drag coefficient. The annular was chosen because the average of the range was the highest. The annular also has an advantage of using less fabric as each individual gore is smaller due to the size of the vent hole.

Sizing

The terminal velocity of each rocket section was calculated by

$$V = \sqrt{\frac{2Eg_c}{m}} \tag{20}$$

where E is the maximum landing energy, this value is lower than what is stated in the statement of work (SOW) due to the hard landing surface., is the total mass of the section to be recovered (lb_m), and g_c is the dimensional constant. The steady state velocity under parachute is calculated by

$$V = \sqrt{\frac{2mg}{\rho C_d A}} \tag{21}$$

where g is acceleration due to gravity, ρ is the density of air, C_d is the drag coefficient of the parachute, and A is the parachute area including vent holes and openings. By combining equations 1 and 2 the area can be calculated by

$$A = \frac{m^2 g}{\rho C_d E g_c} \tag{22}$$

The nominal diameter is then determined by

$$D_0 = \sqrt{\frac{4A}{\pi}} \tag{23}$$

Table 5 shows the estimated mass, total parachute area, nominal diameter, and landing velocity for the launch vehicle sections and hazard detection payload.

Section	E (ft-lbf)	m (lb's)	A (ft)	D_0 (ft^2)	V (ft/s)
Booster	60	15.9	62.567	8.9254	15.583
Lower Sustainer	60	18	80.185	10.104	14.646
Upper Sustainer	60	14.7	53.479	8.2518	16.206
Hazard Detection Payload	25	5.5	17.967	4.783	17.102

Table 5. Vehicle mass, parachute area, parachute diameter, and landing velocity.

This value of D_0 was used to determine the individual gore dimensions as shown in Figure 22.

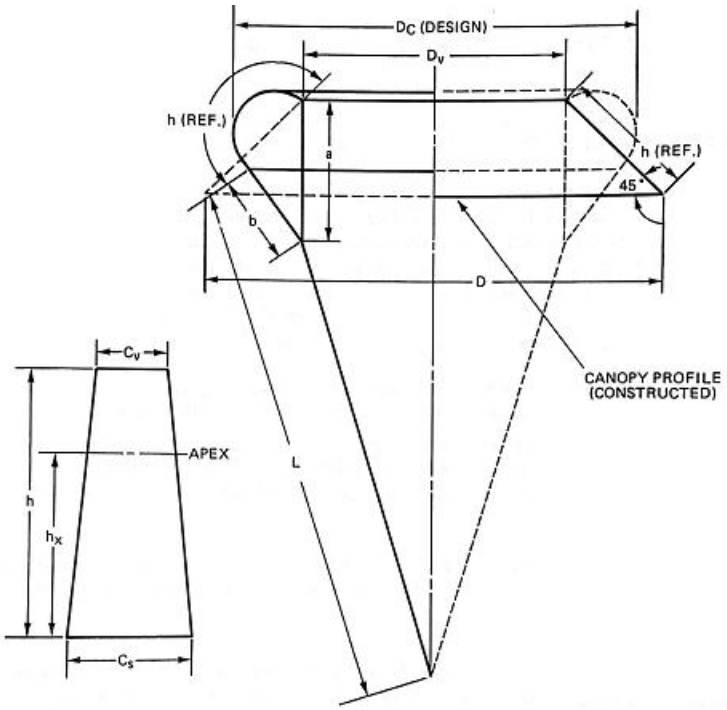


Figure 22. Parachute and gore layout.

The general gore dimensions and parameters are shown in Table 6.(Knacke 6-23).

Dimension	Ratio, D_0
D	1.040
D_C	0.940
D_V	0.611
L	1.250
h	0.304
hx	0.209
a	0.319
b	0.200

Table 6: Parachute gore dimensions.

C_V is then calculated using

$$C_V = \frac{\pi D_V}{N_G} \tag{24}$$

where N_G is the number of gores. C_S is then calculated using

$$C_S = \frac{\pi D}{N_G} \tag{25}$$

Using equations 24, 25, and the ratios shown in Table 6**Error! Reference source not found.** all relevant construction dimensions and the results are shown in

Rocket Section	Ng	Cv (in.)	Cs (in.)	h (in.)	a (in.)	b (in.)
Booster	10	20.56	33.65	32.56	34.17	21.42
Lower Sustainer	10	23.27	38.09	36.86	38.68	24.25
Upper Sustainer	10	19.01	31.11	30.10	31.59	19.80
Hazard Detection Payload	10	11.02	18.03	17.45	18.31	11.48

Table 7: Nominal parachute dimensions.

Construction

The canopy will be made of MIL-C-44378 0.75 oz. rip stop nylon; the reason this material was chosen is because the team had success using it last season. The suspension lines will be made of 1/8th inch nylon para-cord with 400 lb tensile strength. The harness that connects the suspension lines to the launch vehicle will be made of 9/16th inch tubular nylon with a tensile strength of 500 lbs, there will be one harness per parachute. There will be ten suspension lines per parachute as each parachute has ten gores.

To account for the loss of fabric during hemming and sewing the panels together the cut dimensions must be greater than the characteristic dimensions listed previously. Figure 23**Error! Reference source not found.** shows the hem layout. The shown dimension H will be ½ inches, so a total of two inches will be added to the total height of each gore.

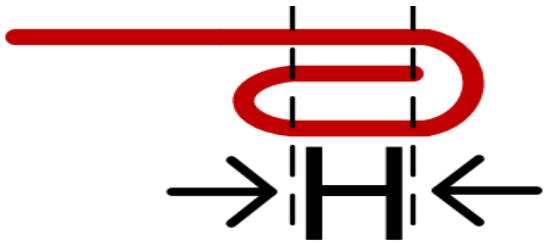


Figure 23: Hem layout.

The individual gores will be sewn together in a French felled seam, also known as a double lap seam, as shown in Figure 24. The shown dimension “S” will be ½ inch so a total of 1.5 inches will be added to both C_s and C_v for each gore.

Figure 24: Added fabric due to stitching

Seam Construction

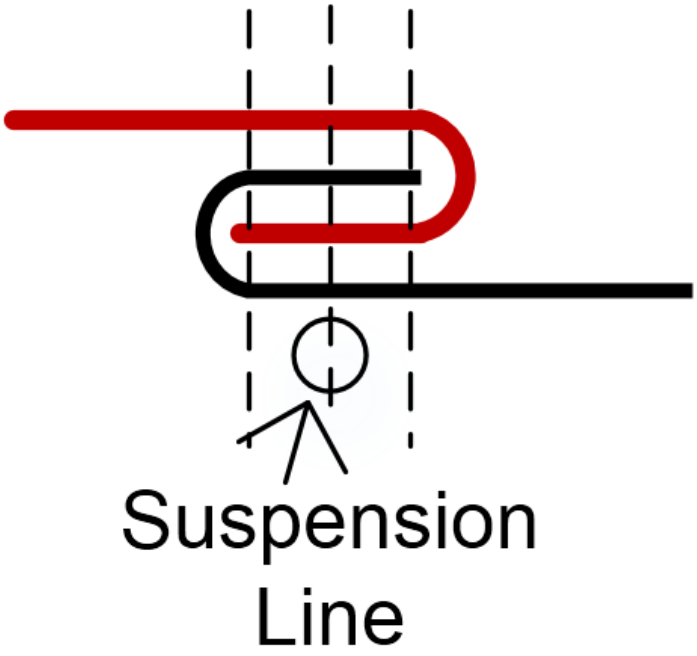


Figure 25: Seam that will connect each gore panel together.

As stated previously the seam that will hold the parachute together will be the French felled seam, it will consist of two straight stitches running along the outer edge of the seam as shown by the two outermost dashed lines in Figure 25**Error! Reference source not found.**. A third stitch will run along the center of the seam that will connect suspension line sleeving to the edges of the parachute and will form permanent attachment points for the suspension lines.

After each gore has been hemmed along the edges that do not connect to another panel a flat panel will be laid out. At the outer edge of the panel a layer of ½ inch double sided seam basting tape will be applied, this is to ensure that the panels are perfectly aligned when sewing.

Figure 26: Applying seam tape to gore panel.

Then the other panel will be aligned next to the edge of the seam tape, once the alignment is finished the original panel will be folded over the added panel to hold them in place. The second panel will be then folded over to complete the seam.

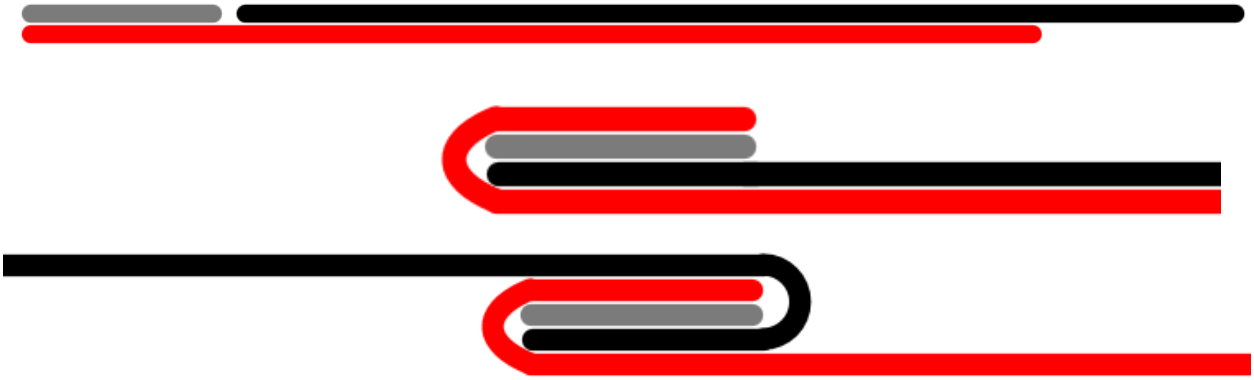


Figure 27: Seam construction.

Suspension Line Attachment

The suspension lines will be attached to the parachute via sewn in attachment loops. The loops will be made of suspension line sleeving and will be sewn in as shown in Figure 28. Six inches will be sewn up the edge of the panel to maintain strength. This will allow for all suspension lines to be removable in the event of damage to the lines or the canopy.

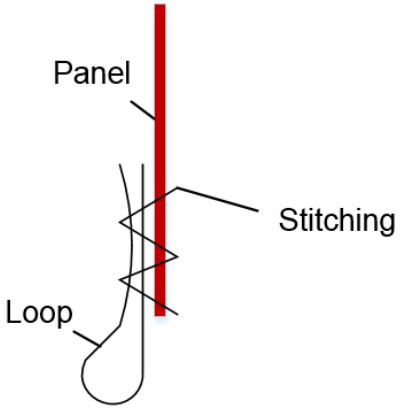


Figure 28: Parachute suspension line attachment design.

Requirement	Verification
The parachute system(s) shall be designed and manufactured by the team. Commercially available parachute systems shall not be used on the vehicle.	The raw material will be purchased through vendors but the construction of the parachute will be done by students as described above.
At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lb$_f$.	The size of each parachute has been determined to keep the maximum kinetic energy below 60 ft-lb$_f$ based on the experimentally determined drag coefficient of the parachute geometry. The landing kinetic energy has been set lower due to the hard landing surface.
At landing the hazard detection payload at a landing kinetic energy less than 25 ft-lb$_f$.	The size of the parachute has been determined to keep the maximum kinetic energy below 25 ft-lb$_f$ based on the experimentally determined drag coefficient.

Table 8. Parachute verification.

Recovery Harness

The booster, lower sustainer, upper sustainer, and hazard detection payload will all have recovery harnesses, the booster and lower sustainer will be described here and the upper sustainer will be described in the fairing payload section with the harness for the hazard detection payload being described in the payload section.

Booster Harness

The booster harness consists of a 2 inch wide 6061 T6 aliminum U-bolt, steel 3/16 inch eye-bolt, 9/16 inch tubular nylon shock cord, deployment bag, and pilot parachute. The eye bolt is part of the hardware that comes with CTI pro 75mm motor casings and the shock cord will be attached via carabineer and sown in aluminum ring. The shock cord will also be attached to a separate aluminum ring which will attach to the shock cord that comes from the stage separation coupler as shown in

At the top of the shock cord will be a swivel sewn into the shock cord. The other end of the swivel will attach to an aluminum ring which will have all of the parachute suspension lines. Those suspension lines will be lines through the deployment bag as to avoid tangling during operation

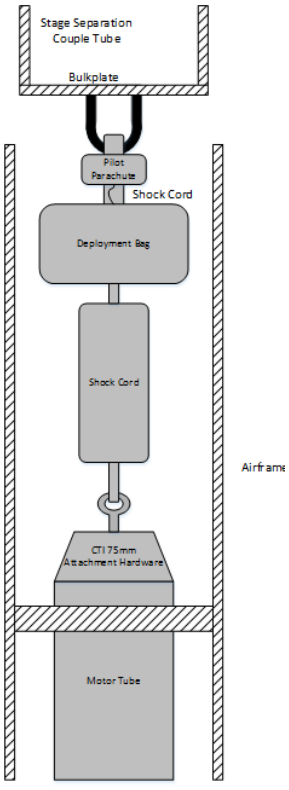


Figure 29: Booster harness.

Above the deployment bag will be a small pilot parachute which will be a student created 1 ft. cross parachute, the purpose of the pilot parachute is to pull the deployment bag and allow the full parachute to deploy successfully.

Lower Sustainer Harness

The harness for the lower sustainer consists of a 2 inch wide 6061 T6 aluminum U-bolt attached to the bulkplate through washers and hex nuts on both sides. Immediately attached to the U-bolt will be a carabineer. The carabineer will also be attached to a 1/8 inch aluminum ring which has shock cord sewn into it. The reason the shock cord was sewn is to provide strength as a sewn connection is stronger than a tied connection and with the carabineer still allows for the shock cord to be removable when needed.

At the top of the shock cord will be a swivel sewn into the shock cord. The other end of the swivel will attach to an aluminum ring which will have all of the parachute suspension lines. Those suspension lines will be lines through the deployment bag as to avoid tangling during operation. Because this section does not have anything to pull on the deployment bag the bag itself will be connected to an eye bolt on the bottom of the fairing payload so when the lower sustainer is ejected the separation of the two vehicle sections will open the bag allowing the parachute to function.

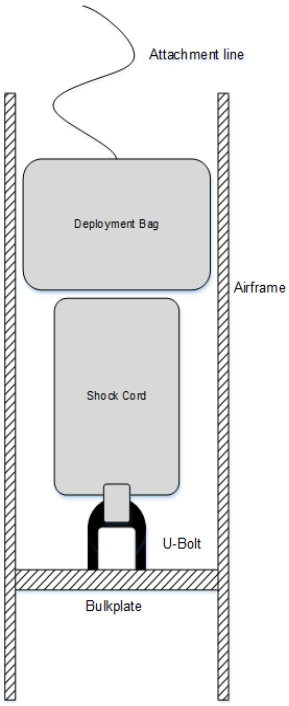


Figure 30: Lower sustainer recovery harness

Hardware

PerfectFlite Stratologger Altimeter

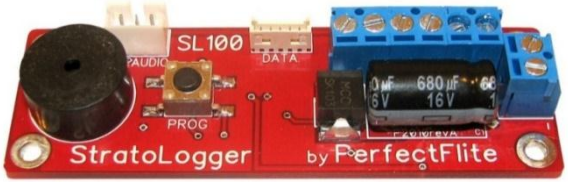


Figure 31: PerfectFlite Stratologger

The PerfectFlite Stratologger altimeter is a common altimeter used in high powered rocketry. It records its altitude at a rate of 20Hz with a 0.1% accuracy. In previous testing, the altimeter was found to be accurate to ±1 foot. The StratoLogger can be configured to provide a constant serial (UART) stream (9600 baud rate ASCII characters) of the device's current altitude over ground. The device can be safely powered by a 4V-16V source and requires 1.5 mA typical, 10A maximum (when activating e-matches).

Featherweight Raven Altimeter

Figure 32. Featherweight Raven.

The Featherweight Raven altimeter records its altitude at a rate of 200Hz via accelerometers and at 20Hz using a pressure transducer with a 0.3% accuracy. The Raven will be powered by its own Featherweight Power Perch which also features a magnetic switch which will be used to lock the altimeter in the on position externally. The device is rated at 30+ amps for air – start applications.

MissleWorks RRC3 Altimeter

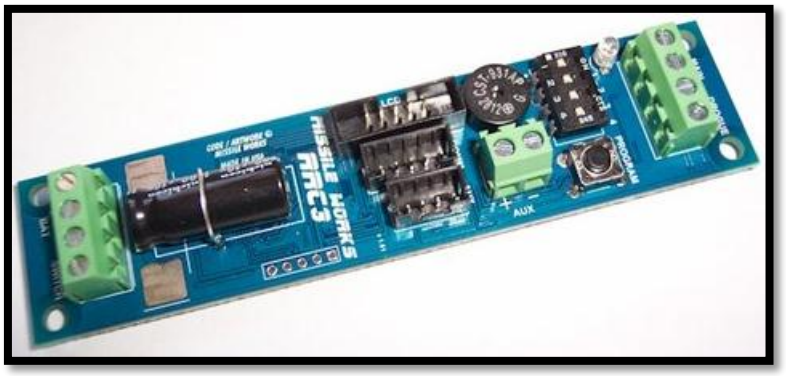


Figure 33: MissleWorks RRC3 Altimeter.

The MissleWorks RRC3 altimeter records data at a rate of 20Hz using a pressure transducer. It will be powered via an external 9-Volt Duracell battery. This altimeter has three outputs, an apogee event, descent altitude event, and an auxiliary event.

Garmin Astro DC 40

Figure 34. Garmin Astro DC 40 GPS Tracker

A Garmin Astro DC 40 will be used to track the booster, lower sustainer, and nose cone rocket sections. The system consists of both a handheld receiver and transmitter unit. The unit will be taken off of the collar and attached to each section. The unit advertises a seven mile range and updates location every five seconds.

GPS/GPRS Cape

Figure 35: GPS/GPRS Cape.

More information on the GPS/GPRS Cape can be found in the Hazard Detection Payload Criteria.

Requirement	Verification
Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.	The nose cone, booster, and lower sustainer will have a Garmin Astro DC 40 dog collar and the hazard detection payload will utilize a GPS/GPRS cape.
The electronic tracking device shall be fully functional during the official flight at the competition launch site.	The GPS cape can be tested by verifying that GPS coordinates are being sent to the ground station. The Garmin Astro DC 40 collars can be verified to be working by verifying position with the handheld receiver.

Table 9. GPS verification

Tiltometer

The goal of this device is to sense the inclination of the rocket with respect to the Earth's surface in order to prevent the rocket from firing its second stage motors at an un-safe angle. After PDR, it was determined that an extra safety measure needs to be added to the rocket to ensure that it does not fire its second stage engine at an unsafe angle. For example, if a gust of wind rotates the rocket, firing the second stage motor can be dangerous. The team is creating their own system since the commercial options, such as the RocketTiltometer, are all currently unavailable or very expensive. The circuit and the

software to run it are all custom made and will run on an Arduino UNO platform. To achieve this, a PCB is being created that will mount on top of the Arduino's pins.

Tiltometer Layout

At a high level, the tiltometer is made of only a couple components as shown below.

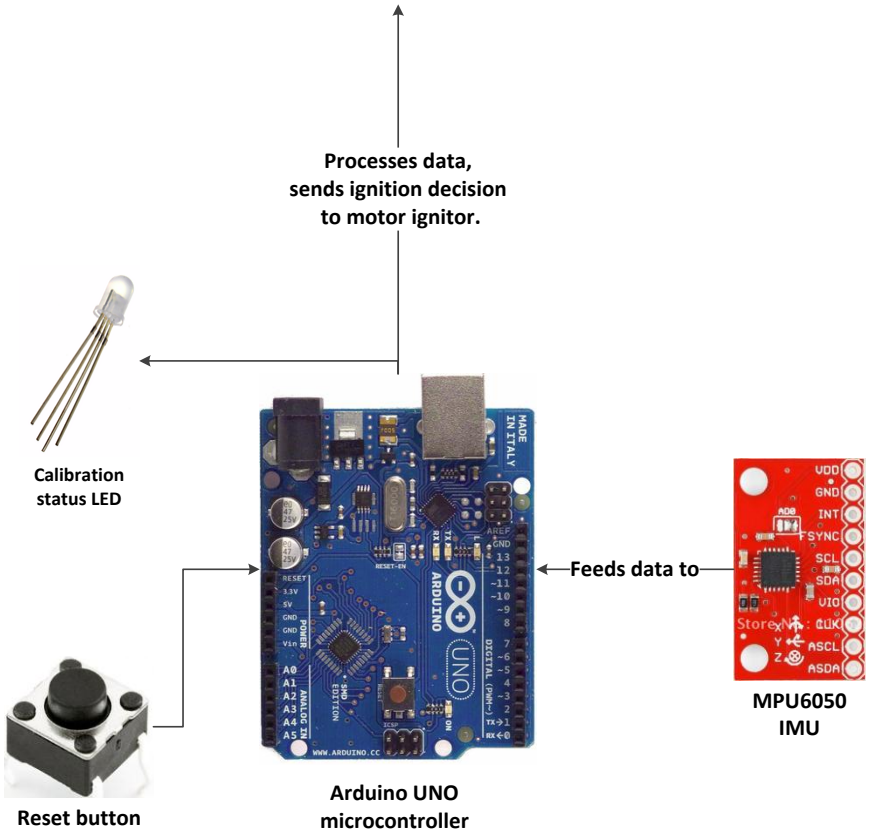


Figure 36: Tiltometer components

The MPU6050 is an IMU (Inertial Measurement Unit) that provides information on its current orientation to the Arduino UNO microcontroller. Currently the team is using a breakout board of the MPU6050, but it will eventually be part of the Tiltometer PCB discussed later. The MPU6050 provides its current orientation in terms of the device's angle with respect to the X-, Y-, and Z-axes. The microcontroller takes the raw angular information from the MPU6050 and updates an internal estimate of the device's actual orientation. Then, the tiltometer determines whether or not the rocket is tilted more than 40 degrees away from the Z-axis. If the rocket is tilted more than 40 degrees from the axis normal to the Earth's surface (the Z-axis, in our case), the processor sends a signal disallowing firing the second stage motor. Otherwise, the microcontroller sends a signal indicating that firing the second stage motor is safe.

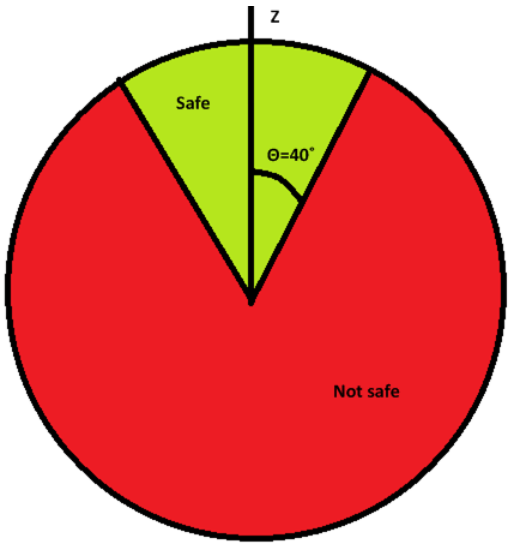


Figure 37: Tiltometer firing ranges. Red=safe to fire. Yellow=not safe to fire. Z is perpendicular to Earth's surface.

The tiltometer also contains a reset button, and a calibration status RGB LED. The reset button is used to reset the tiltometer program, so that calibration estimates are accurate on the launch pad. Whenever the reset button is pressed, the tiltometer will restart its primary program to obtain updated calibration parameters. The calibration status LED indicates to the team whether or not device calibration was successful, so that the team can know if the device is safe to use.

Angular estimation algorithm

The algorithm used to calculate the rocket's current inclination involves the following steps:

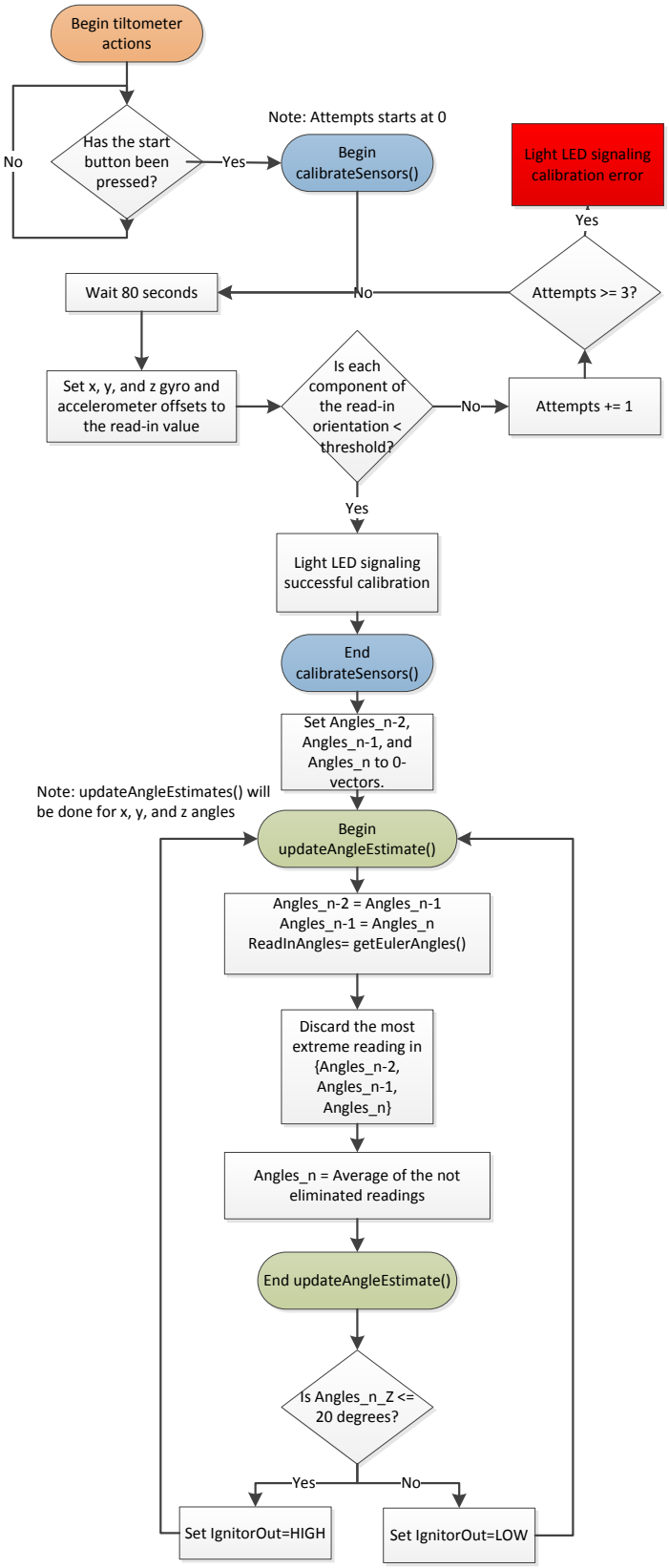


Figure 38: Angle estimation flowchart

Begin tiltometer actions phase

During this phase, the tiltometer will wait until the start/reset button has been pressed by a team member. This ensures that the tiltometer only starts estimating orientation when the rocket is actually on the launch pad.

Calibrate sensors phase

The sensor calibration phase will ensure that the acceleration and gyroscope offsets are properly set on the MPU6050, so that the device's coordinate reference frame is correctly set with respect to the Earth's surface.

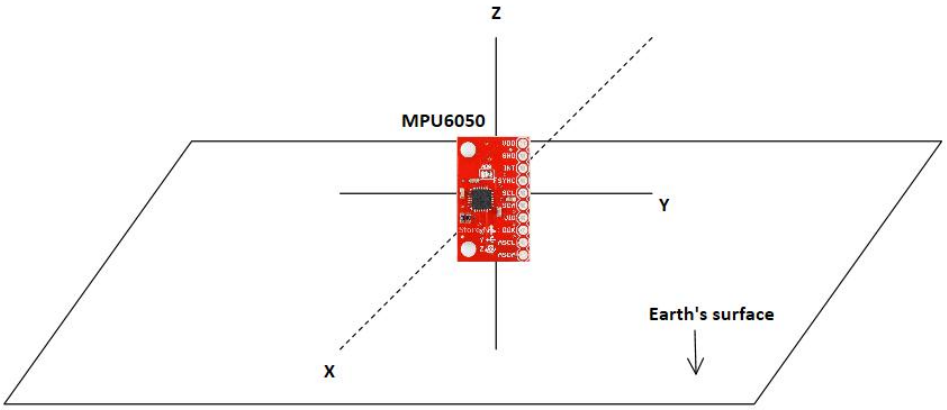


Figure 39: Tiltometer coordinate reference frame

First, the device waits 80 seconds for the device's readings to stabilize at a near-constant level. This time value was determined during testing by the team prior to CDR. After the 80 seconds have elapsed, the tiltometer takes a single reading, and sets its current acceleration and angular offsets to the negative of the reading. For example, if the read in of the acceleration is <1N, 2N, 3N>, the accelerometer's offset would be set to <-1N, -2N, -3N>. This has the effect of making the device's current orientation be the reference point from which future orientation changes are compared.

To verify that the calibration settings are reasonable, the tiltometer will take a single reading from the IMU after the device settings are in place. If the read-in value is larger than a certain threshold determined during testing, it will indicate that the tiltometer is currently in motion, and thus that the calibration settings cannot be trusted. If this event occurs, the calibration phase will restart, up to a maximum of three times to try again. If the calibration phase completes three times without success, a calibration failure LED will be lit to indicate the problem for the team to debug.

Once proper orientation offsets have been entered, the tiltometer begins its primary activity of updating its estimate of its current orientation.

Update angle estimate phase

To update the tiltometer's estimate of the rocket's current orientation, the previous three angle measurements are considered. These measurements are designated:

$Angles_n$ =The angle at time n

$Angles_{n-1}$ =The angle at time n-1

$Angles_{n-2}$ =The angle at time n-2

To determine $Angles_n$, the raw angle measurements are read in from the attached IMU. Then, the most extreme value in the set $\{Angles_n, Angles_{n-1}, Angles_{n-2}\}$ is discarded. To determine which angle is the most extreme, the following calculation is performed:

$$\Delta 1 = |Angles_n - Angles_{n-1}|$$

$$\Delta 2 = |Angles_{n-1} - Angles_{n-2}|$$

$$\Delta 3 = |Angles_n - Angles_{n-2}|$$

valToDiscard=the value common to:{MAX(Δ1,Δ2,Δ3), MID(Δ1,Δ2,Δ3)}

Finally, the current angle estimate [$Angles_n$] is set to the average of the two non-discarded values. This process is done to ensure that if a single angle reading from the IMU is much larger or smaller than the rest (IE: a temporary electrical spike occurs), that angle will not be included in the estimate of the rocket's orientation.

Once the rocket's angle estimate has been updated, the program will check if the angle with respect to the z-axis is greater than 40 degrees. If it is, the program will send an electronic signal disallowing firing of the second stage motor by setting the pin connected to the mosfet low (discussed later). Otherwise, a high signal will be sent allowing firing of the second stage motor.

Test results

The team has verified that the MPU 6050 IMU provides angle data to the Arduino UNO. The team has verified that angle readings are responsive to physical rotations of the device. The team has also verified that readings from the IMU do not drift over short timeframes (<30 minutes). The team has also made significant progress developing the angle visualization test program explained below, and just needs to make a few tweaks to get it working satisfactorily.

Test plan

The team's current testing plan for the tiltometer involves the following tests:

Angle visualization

The team is currently developing a program to visualize in 3D the current orientation of the rocket. This program will display the current angles read in from the tiltometer in real-time by rotating a 3D model. This test will verify that the data coming from the IMU is accurate, and that the calibration step properly calibrates data reading offsets.

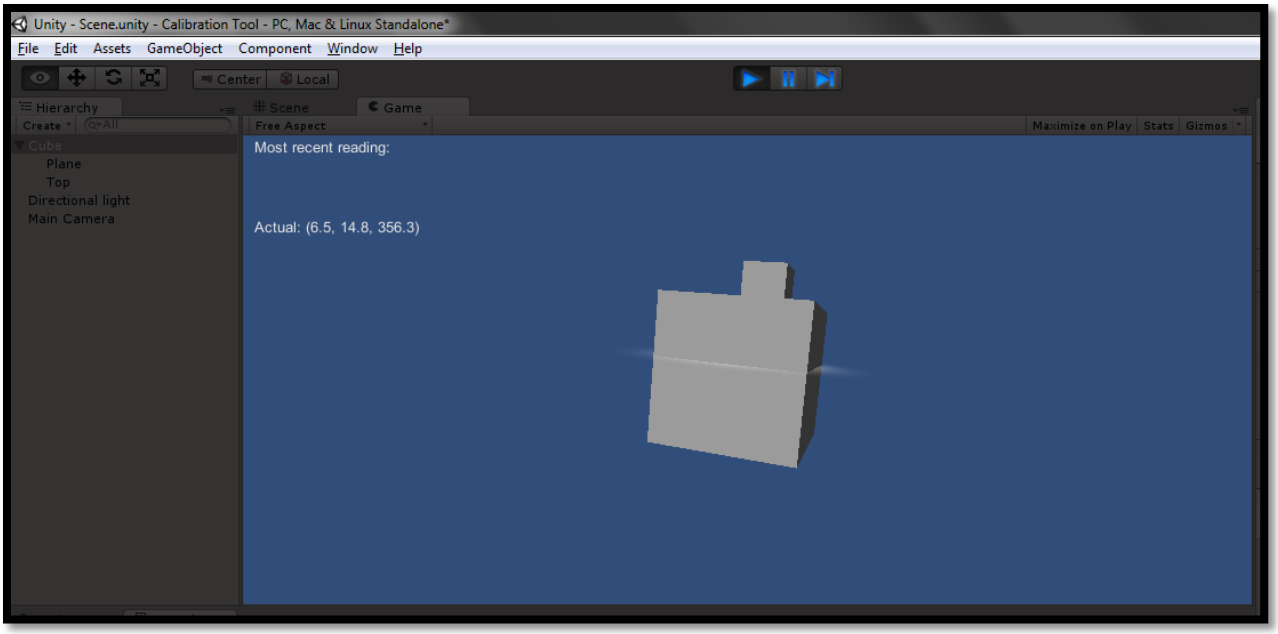


Figure 40: Angle visualization program

Angle drift test

Along with tests to make sure the read-in orientation is accurate, a test will be performed to determine if sensor readings drift significantly over time. The team has already tested this prior to CDR, and did not encounter significant drift in sensor readings over short timescales (<30 minutes). The team plans to leave the tiltometer in the same position for a few hours, and then graph the readings to determine if the sensor drifts over longer timeframes. If significant sensor drift is encountered, the tiltometer algorithm/settings will be modified to eliminate the drift.

Angle safety detection test

Once the angle visualization test is completed, the team verify that, when the tiltometer is angled at an unsafe angle, the second stage will not be fired. To do this, an LED will be connected to the device, and a program will be written that, when the tiltometer is angled at an unsafe angle, turns the LED on, and when the tiltometer is at a safe angle, turns the LED off. This test will verify that the program correctly identifies safe vs unsafe angles, and that the signal to disable the second stage motors (simulated via the LED) will behave properly.

Electrical System

The tiltometer's basic function will be to read angle values from an accelerometer and gyroscope, and based on the angle it will allow current to flow from a Raven altimeter to the motor igniter or block it. An MPU6050 IC will be used to read angles since it contains a 3-axis accelerometer and gyroscope in one package which simplifies the circuitry. The electrical schematic of the current tiltometer revision is shown in Figure 41.

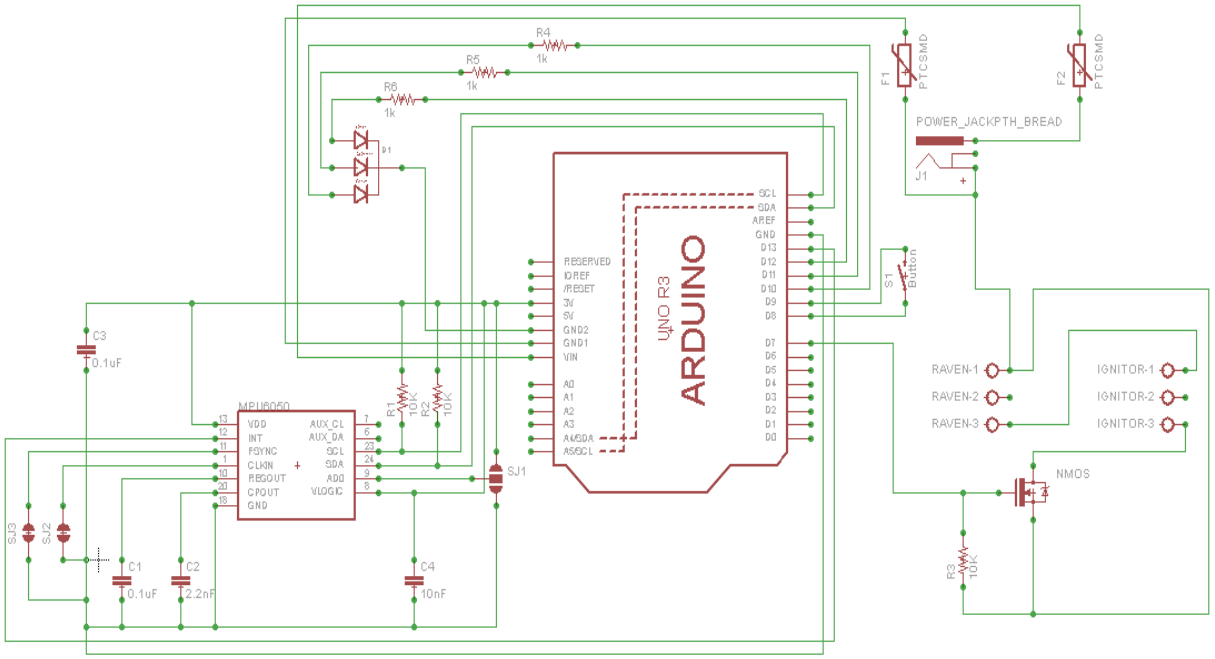


Figure 41: Tiltometer's Electrical Schematic.

The MPU6050 IC uses I2C communication protocol which reduces the amount of pins needed on the Arduino compared to UART or SPI communication. This chip operates from 2.375-3.46V which is why it is tied to the Arduino's 3.3V power bus. Some of the technical specifications of the accelerometer and gyroscope are shown in Table 10.

Parameter		Accelerometer	Gyroscope
Range		±2g, ±4g, ±8g, ±16g	±250 º/s, ±500 º/s, ±1000 º/s, ±2000º/s
Sensitivity	X-axis	±50mg	0.1 º/s/g
	Y-axis	±50mg	0.1 º/s/g
	Z-axis	±80mg	0.1 º/s/g
Frequency	X-axis	1000Hz	33kHz
	Y-axis	1000Hz	30kHz
	Z-axis	1000Hz	27kHz

Table 10. Specifications for Accelerometer and Gyroscope on the MPU6050 IC.

The circuit for the MPU6050 IC has been already been proven to work as a standalone system using a breakout board with the Arduino. Further testing will be done once the Tiltometer PCB is manufactured and assembled.

The method this circuit works is that the Raven's output will be connected to the input terminal block on the Tiltometer's PCB, and the motor's igniter will be connected to the output terminal block. An N-channel mosfet will act as a switch to allow the current from the Raven to flow to the igniter as long as the Arduino keeps a high signal output on the mosfet's gate. An FQP30N06L mosfet is being used as it is rated for 60V and 30A which is more than what the Raven will output.

If the MPU6050 IC detects the angle is greater than 40 degrees, the Arduino will pull the signal low on the mosfet's gate. This will cause the mosfet to switch off and no current will flow to the igniter. If the angle is less than 40 degrees, the mosfet will stay on. The mosfet circuit has been tested to work on its own and further tests will be done to insure it works with the entire system.

The 30A current should not be seen by the Arduino, but in case the current does flow to the Arduino, two fuses are at the negative and positive terminals of the power source for the Arduino. The fuses will blow if the current going to the Arduino exceeds 7A, therefore protecting it from being fried.

The circuit will also include a reset button and an RGB led to indicate the status of the Tiltometer. A 9V battery is currently expected to power the Arduino and the attached Tiltometer PCB. The current layout of this PCB is shown in Figure 42.

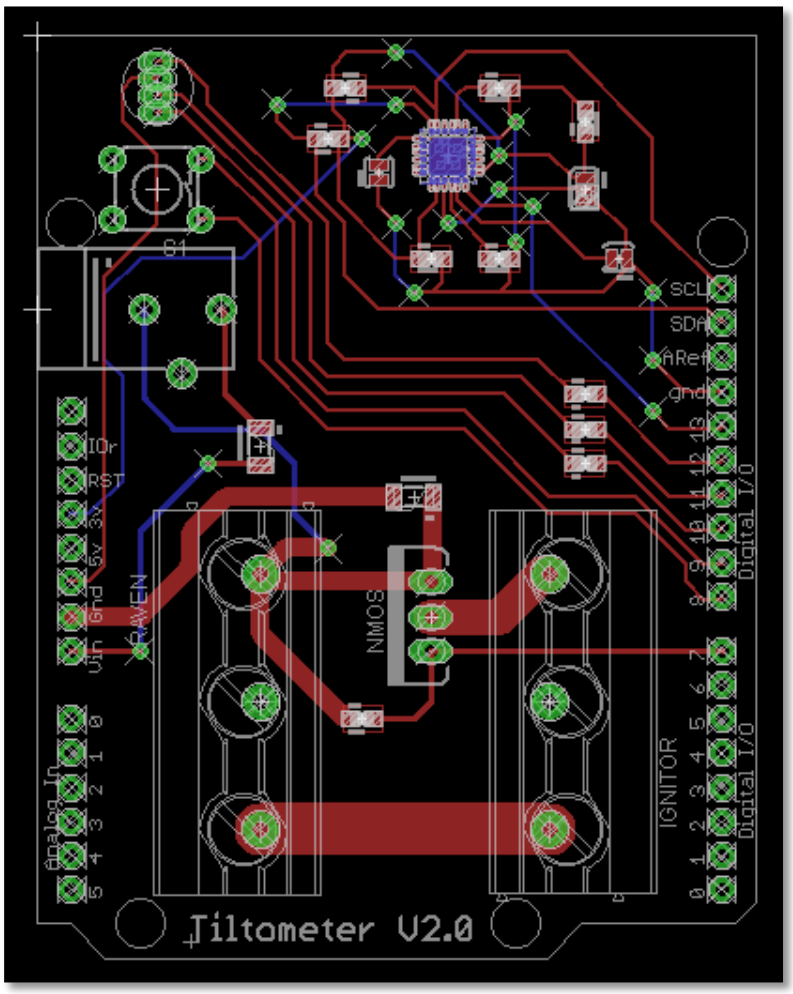


Figure 42. Layout of the Tiltometer PCB.

As can be seen, the circuit for the MPU6050 is as far from the terminal blocks connecting the igniter and Raven. The reason for this is to prevent any parasitic effects on the MPU6050. Both of the terminal blocks are rated for 600V, 30A so they should be able to

withstand the power required to light the igniter. The Tiltometer PCB is able to contain all the components on a board the same size as the Arduino UNO. Therefore, the Tiltometer will only measure 2.7”x2.1” and it will be oriented vertically in the rocket as shown in Figure 42.

Once the Tiltometer’s PCB has been manufactured and assembled, several ground tests will be conducted to insure that it operates as intended before being placed on the rocket. Any further revisions will be documented in later reports.

Flight Path and Recovery Logic

The proposed flight path is shown below in Figure 43 with the events shown in sequential number.

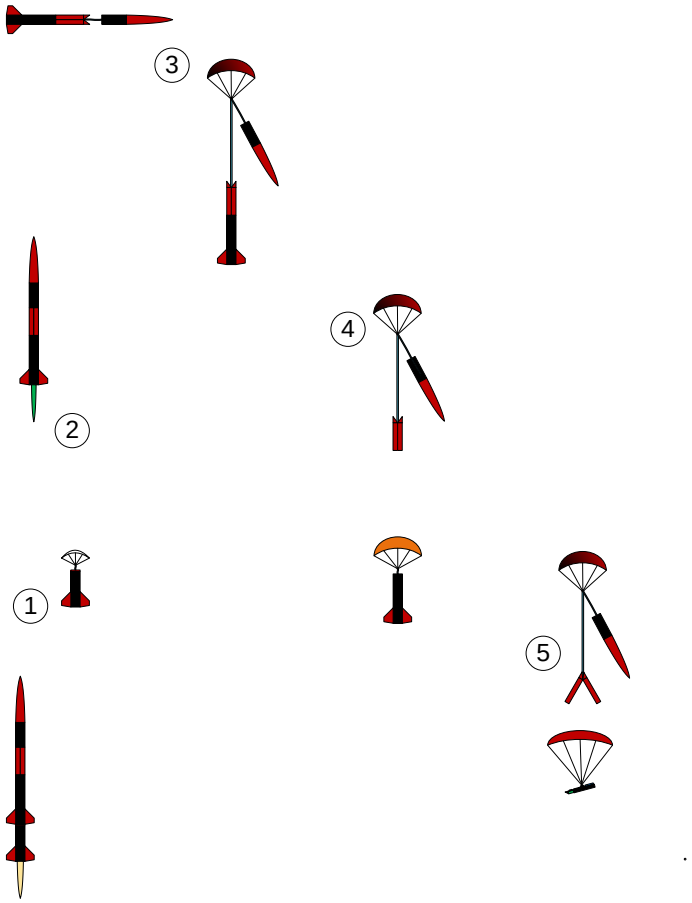


Figure 43: Proposed flight path.

Event one is the stage separation, event two is the second stage motor ignition, event three is the apogee event, event four is the ejection of the lower sustainer, and event five is the opening of the fairing payload and the ejection of the hazard detection payload. Each event is described in more detail in Table 11.

Event	Altitude (ft.)	Description
1	613	Booster motor burnout. Ejection of booster section. Ignition of sustainer after coast time designated in At booster apogee, parachute is ejected.
2	3699	Ignition of second stage motor.
3	10,000	Nose cone ejection. Sustainer under pilot parachute..
4	7500	Lower sustainer ejection. Lower sustainer under parachute. Fairing payload and nose cone under pilot parachute.
	5000	Fairing opens and payload is released. Nose cone descends under initial pilot parachute. Payload descends under parachute.

Table 11. Description of ejection events.

Recovery Logic

Booster Recovery

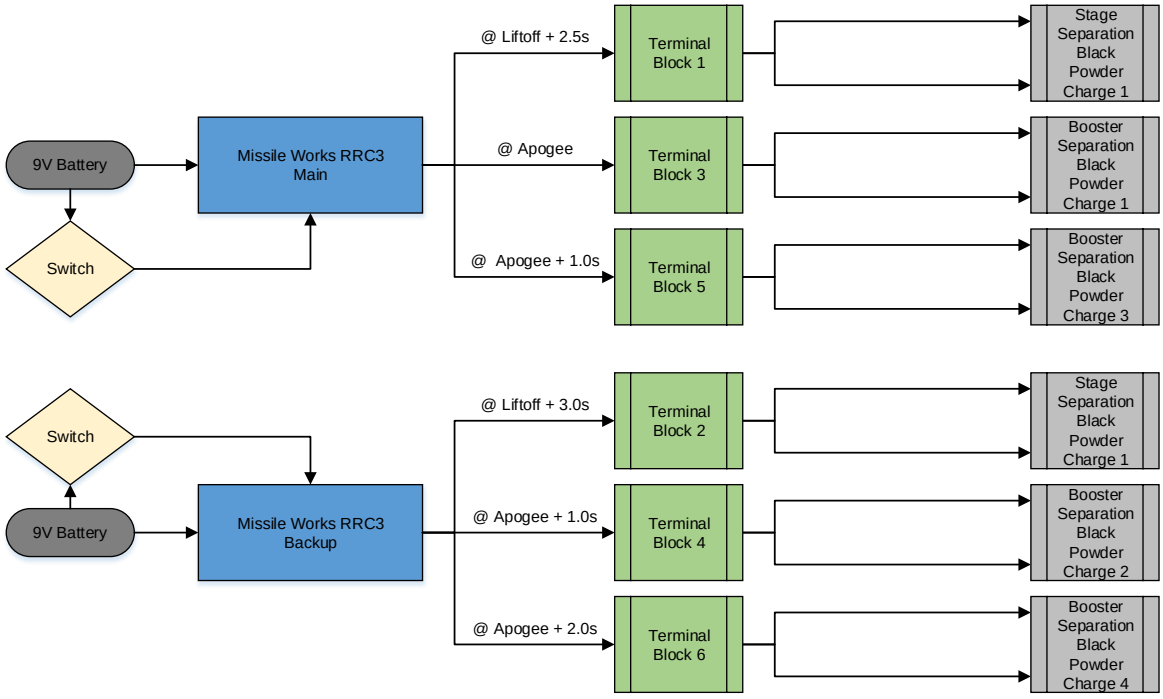


Figure 44: Booster recovery logic.

The booster will be the first section to be recovered, at motor burnout two MissleWorks RRC3's will be used to separate the booster from the sustainer. These altimeters were chosen for being both able to separate the booster and provide redundant recovery events at apogee at half of the price of the Raven. There are two black powder charges at apogee + 1.0 seconds, this is due to the combination of one altimeter being in backup mode and the other being in apogee only mode.

2nd Stage Motor Ignition

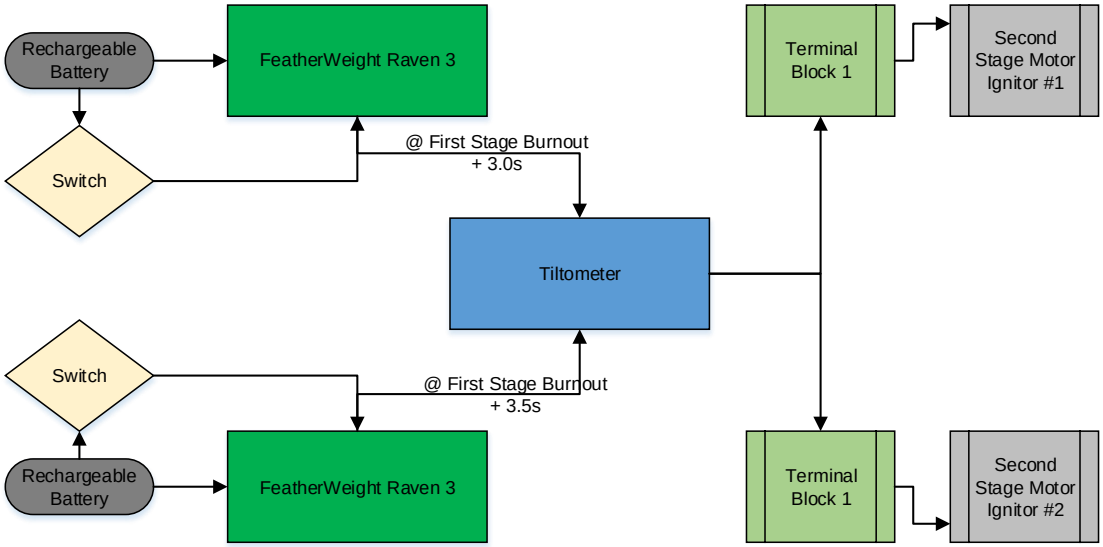


Figure 45: 2nd Stage ignition logic.

Using OpenRocket and taking an iterative approach with the new larger vehicle it was determined that to achieve the highest altitude that the 2nd stage motor will have to provide thrust 3.0 seconds after burnout. In the following flowchart it shows the ejection charge as being 3.0 and 3.5 seconds, those values are placeholders until we are able to statically test the motor. The motor will be tested on a static thrust stand and the time taken from sending the ignition signal until the motor produces thrust will be documented and then subtracted from the 3.0 second delay. Two ignitors will be used with one from each Raven for redundancy.

Apogee Event.

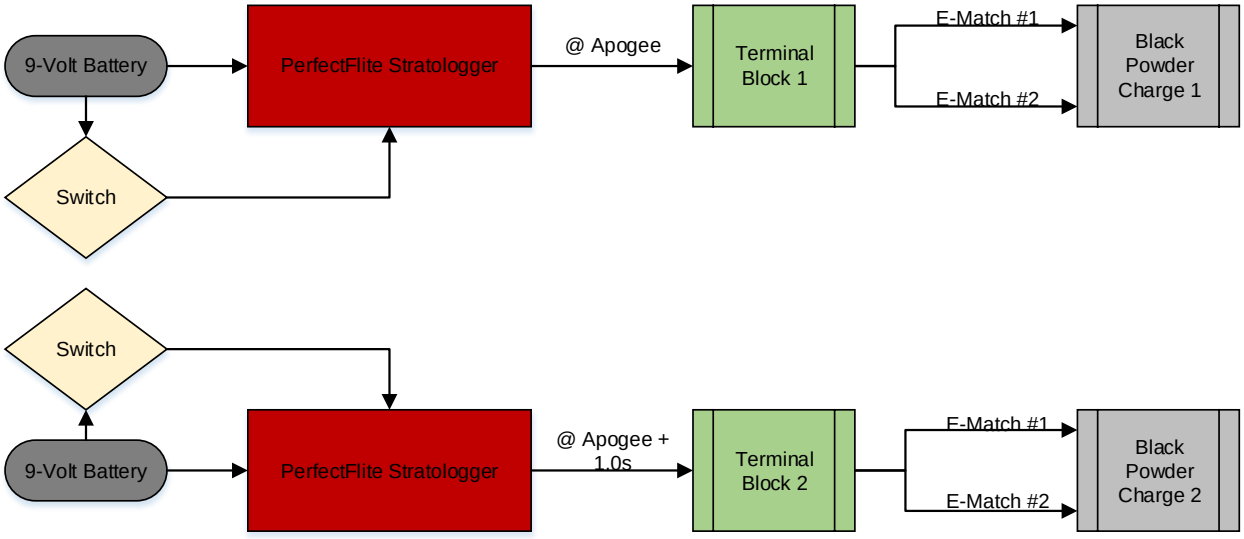


Figure 46: Apogee recovery logic.

The apogee event uses two Stratologger's that deploy at apogee and apogee + 1.0 seconds. This is a standard dual deployment for high powered rocketry.

Lower Sustainer Ejection

The lower sustainer will be ejected at 7500 ft. and will be under parachute when ejected. The same Ravens that powered the motor ignition will power the black powder charges to separate the lower sustainer from the fairing payload.

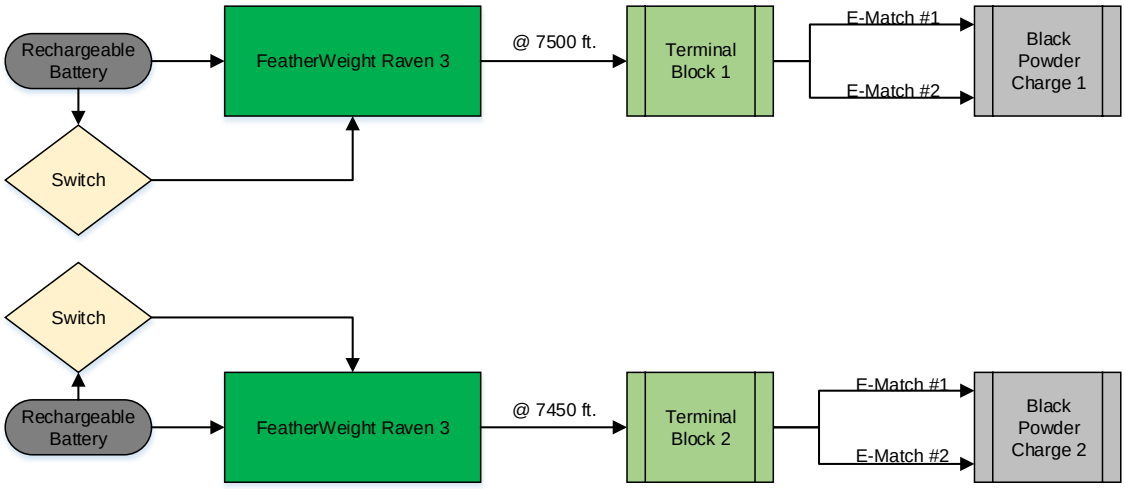


Figure 47: Lower sustainer recovery logic.

Requirements	Verification
The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.	The main parachute for the nose cone will act as a drogue until the lower sustainer separates under its main parachute. The nose cone parachute will also act as the drogue for the hazard detection payload.

Table 12. Flight path verification.

Avionics Bay

Each section that will be recovered will have its own custom designed altimeter sled and corresponding avionics bay. This section will cover the avionics bays for the booster recover, apogee event, and lower sustainer ejection, the rover ejection event will be covered in the fairing payload section. All electronics will be attached to the sled via nylon 4-40 screws, this was done so that in a catastrophic failure the screws shear and the altimeters have an increased chance to survive. All sleds will also be 3D printed out of ABS, this was done to reduce the mass of each of the sleds. After being printed the sleds will go through and acetone treatment to strengthen them.

Universal Components

Battery Holster

The battery holster that houses the 9 – volt batteries will be the same on all described avionics bays. The holster consists of two parts, the base and the cover, that screw into each other using two 4-40 nylon screws. Each component of the battery holster will be printed out of Makerbot ABS plastic, this is done to make the design as lightweight as possible and to allow for custom mounting if needed.

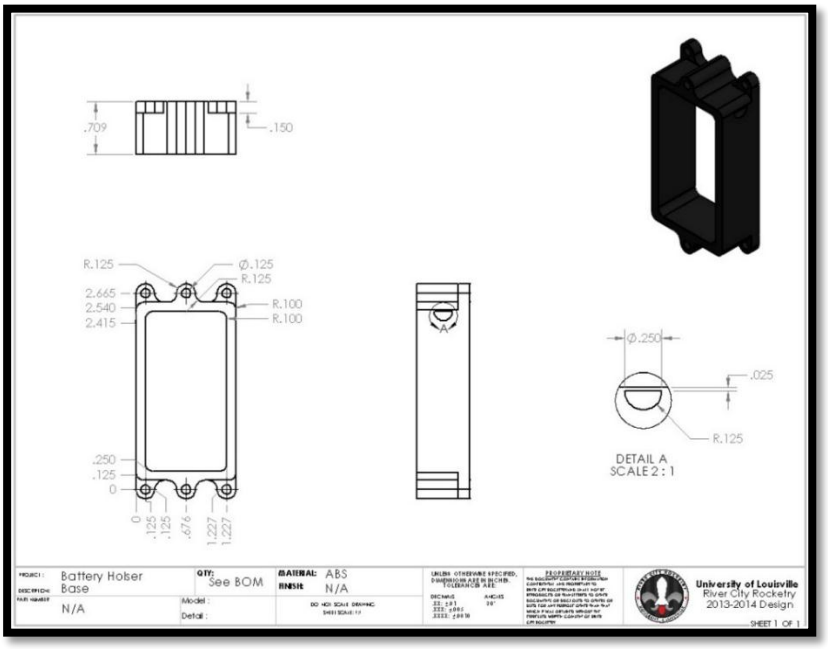


Figure 48: Battery holster base.

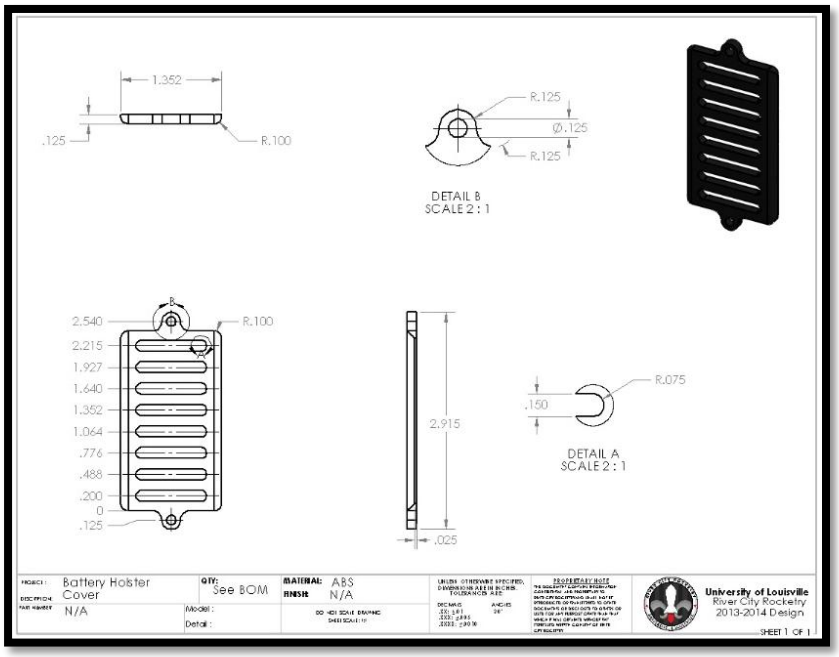


Figure 49: Battery holster cover.

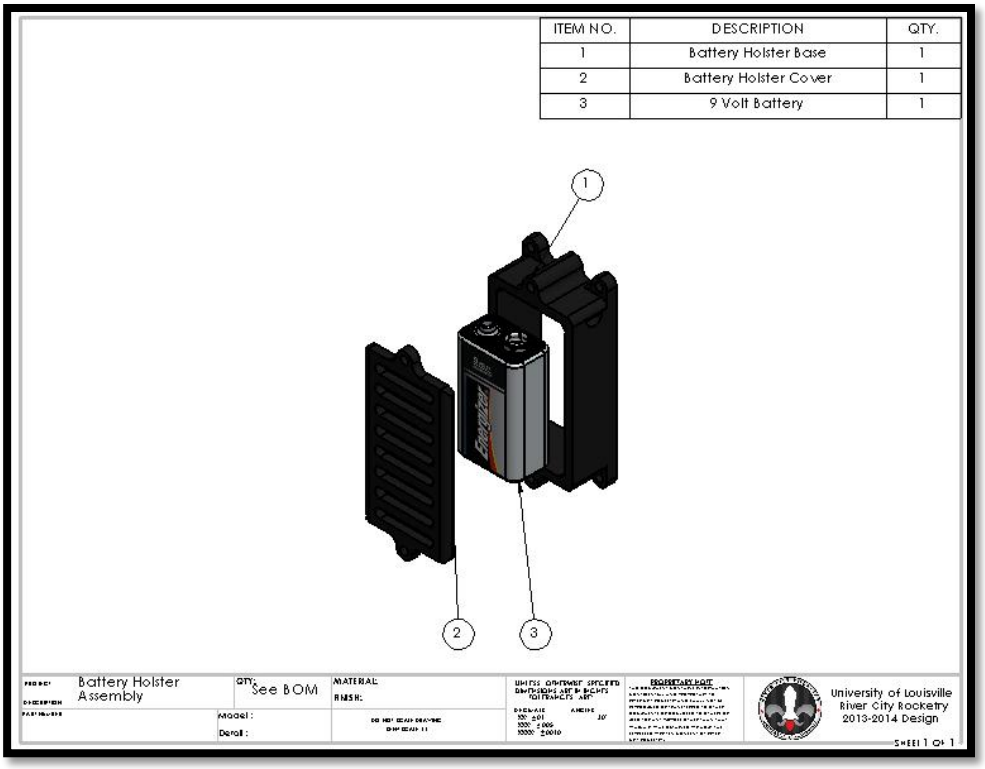


Figure 50: Battery holster assembly.

Booster Avionics Bay

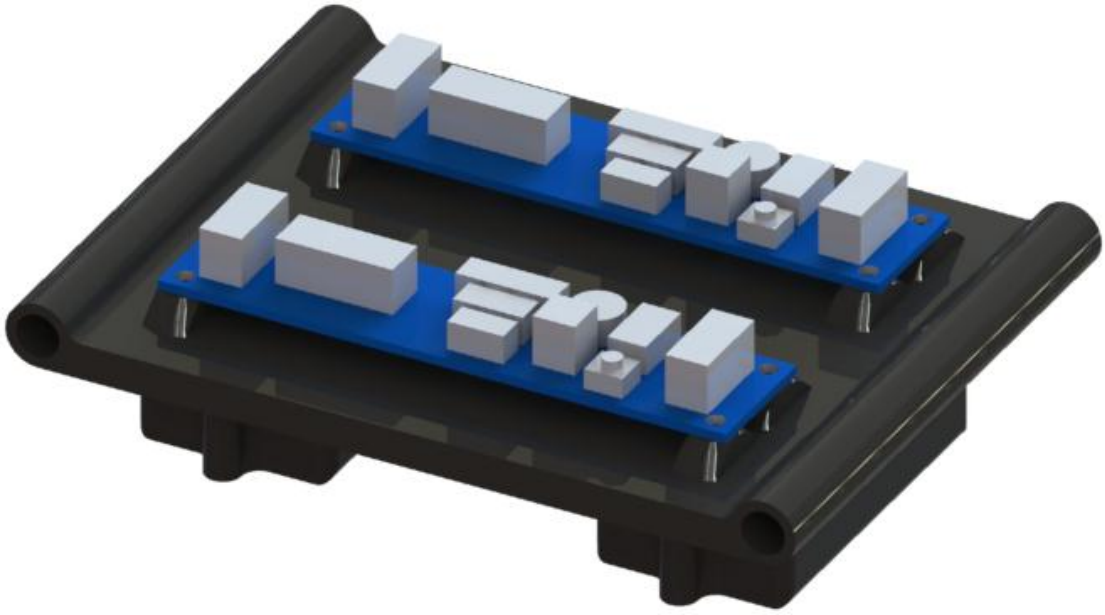


Figure 51: Booster altimeter sled.

The booster avionics bay consist of a sled designated for two battery holsters and two MissleWorks RRC3 altimeters, and the two battery holsters. Standoffs for the altimeters

will be built into the sled and be tapped so the altimeters and the battery holsters screw directly into the sled. This reduces the chance that a small piece can be lost or damaged.

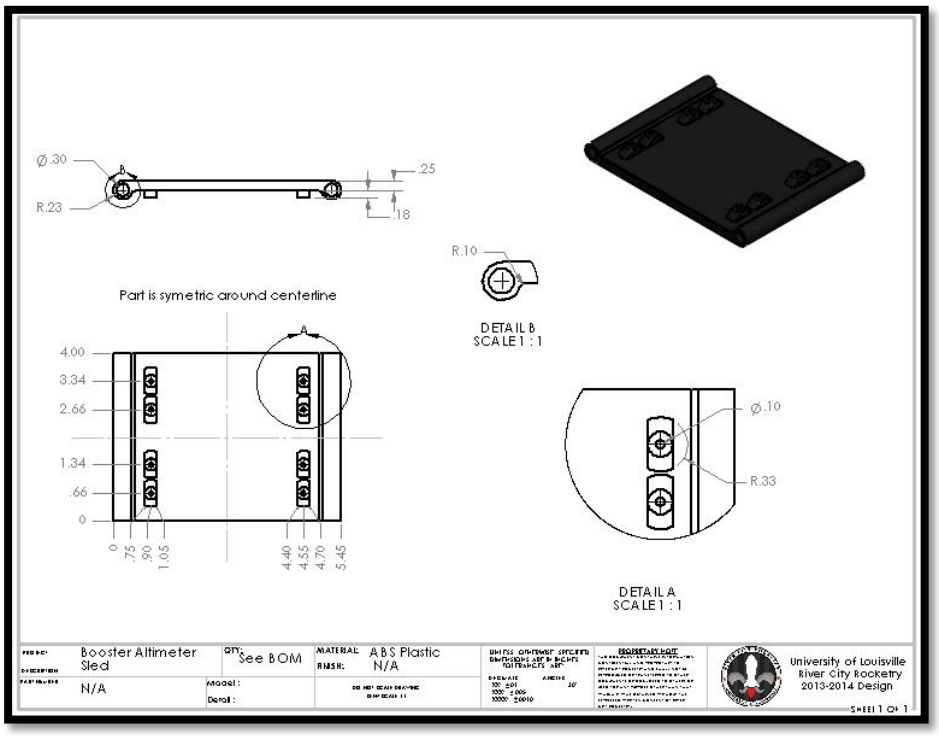


Figure 52: Booster altimeter sled.

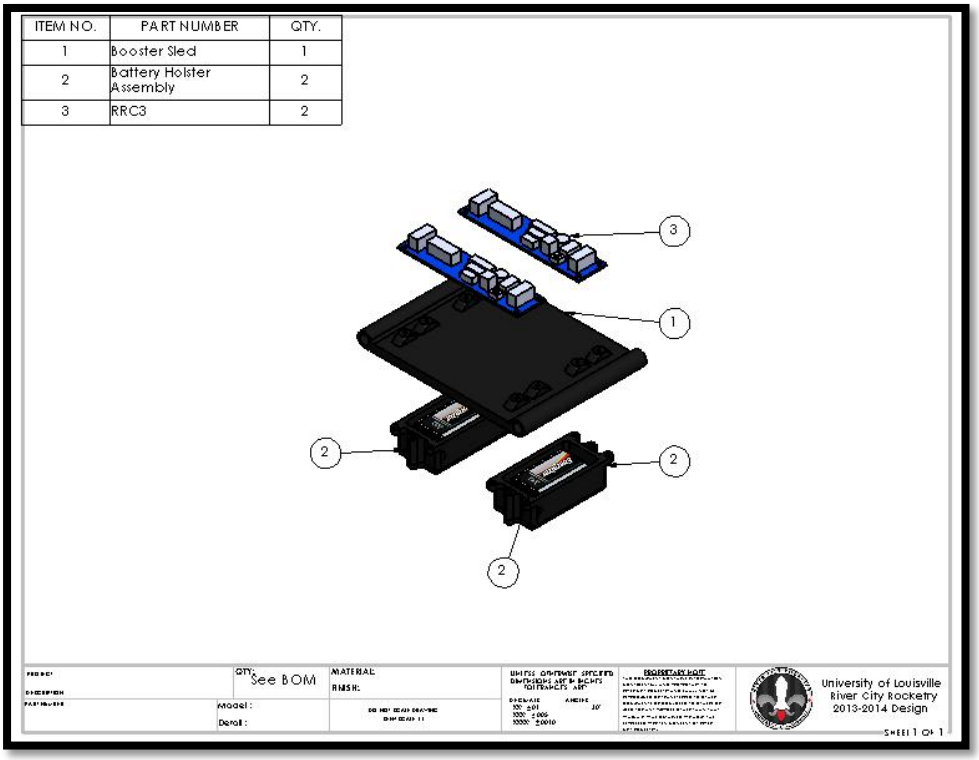


Figure 53: Booster altimeter sled BOM.

The sled will be held in place between two sets of bulkplates via two ¼ inch aluminum threaded rods. The rods had to be placed far enough apart (4.5 inches) to avoid contact with the sustainer motor retainer. To not waste the space between the threaded rods the altimeters will be mounted perpendicular to the vehicles direction of travel, this will not pose a problem as the RRC3 is a barometric altimeter with no orientation dependence.

Lower Sustainer Avionics Bay

Figure 54: Sleds of the lower sustainer avionics bay.

The lower sustainer avionics bay consists of two separate 3D printed ABS sleds, one holds the tiltometer and Raven altimeters, and the other is a mount for a GoPro camera. Both the tiltometer and Raven's will screw in directly to the sled using tapped holes for nylon 4-40 screws. This sled will have to hold two Raven altimeters plus power perches, one Arduino which will function as the tiltometer, and one 9-volt batteries.

The two Raven's will be opposite of the tiltometer and will be activated through the power perch magnetic switch. Last year's team utilized the magnetic switch through the air-frame successfully and during sub-scale testing the magnetic switch was activated through the airframe and thus will not be an issue.

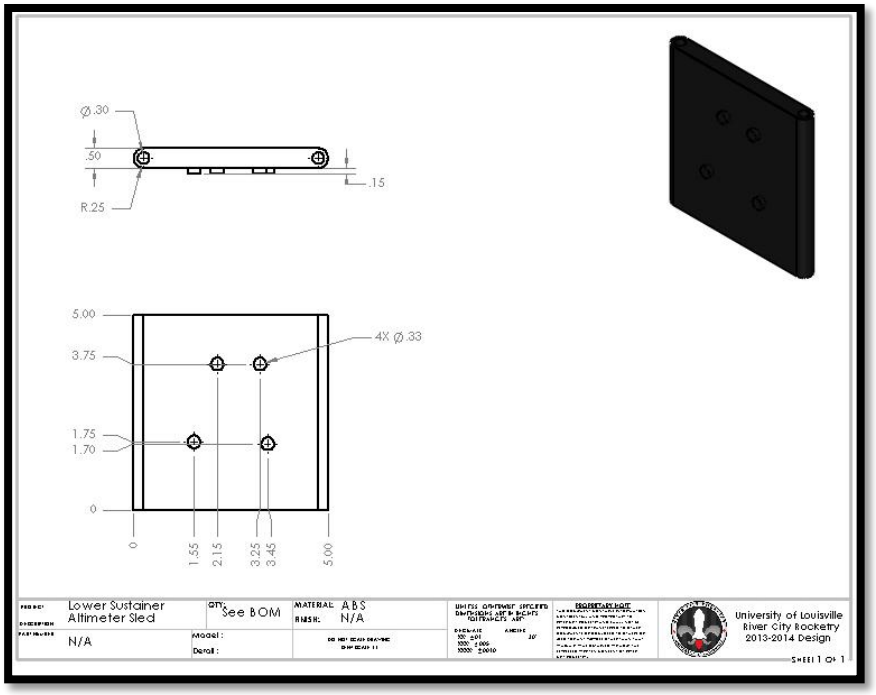


Figure 55: Tiltometer sled.

The GoPro camera mount is beneath a wooden bulkplate that rests underneath of the altimeter sled, the bulkhead will be covered in aluminum tape to shield the altimeters from the GPS unit stationed within the lower sustainer. The GoPro mount consist of one solid piece of 3D printed ABS plastic in which with three additional 3D printed parts that hold the camera into place will be screwed into.

Figure 56: Rendering of GoPro sled.

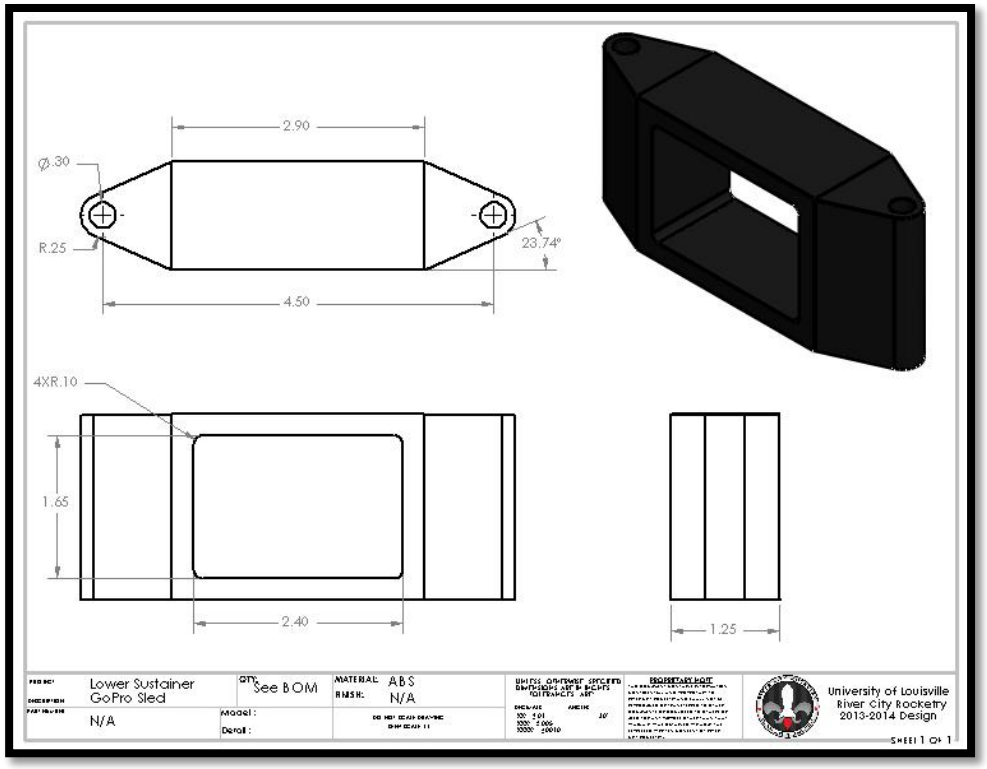


Figure 57: GoPro sled.

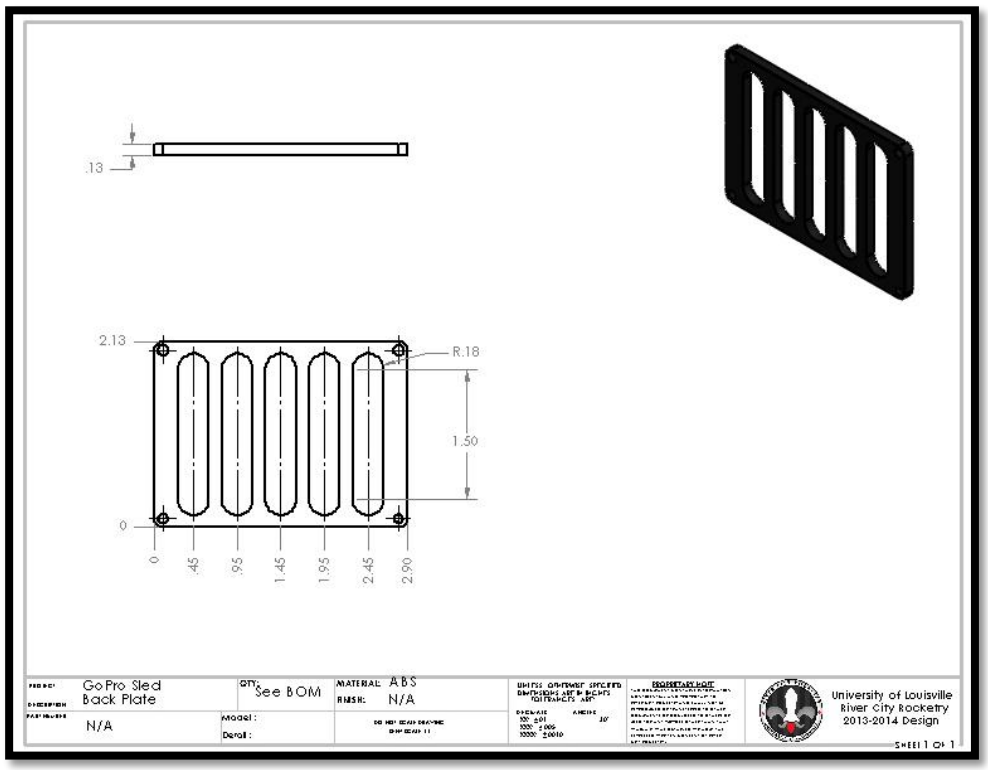


Figure 58: GoPro backplate.

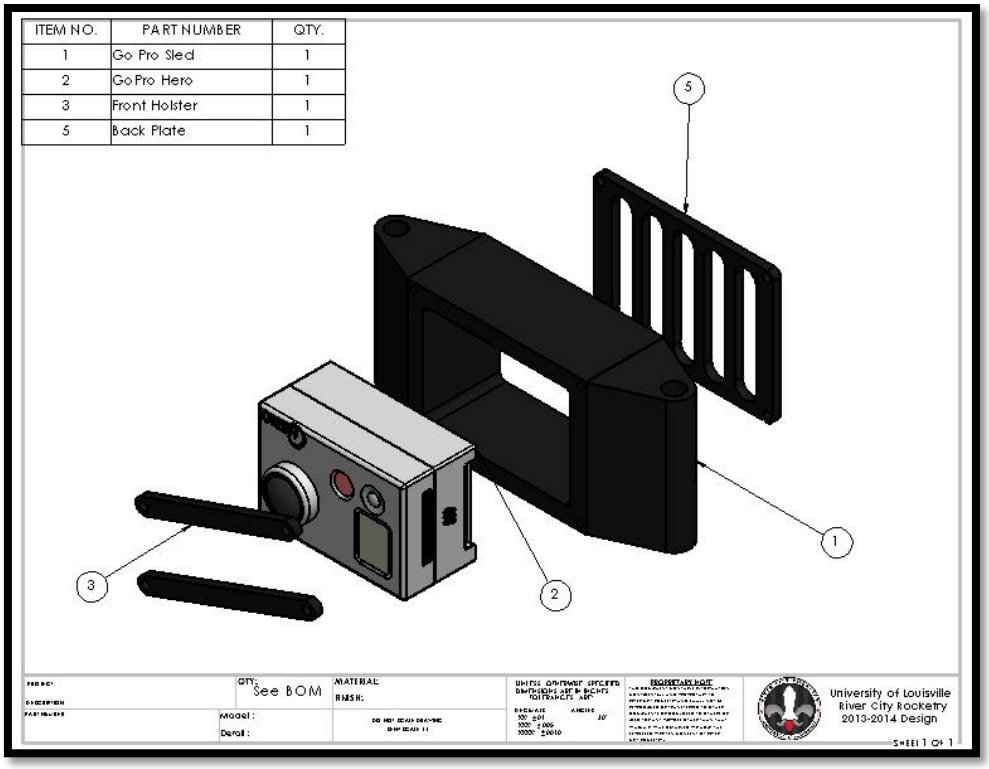


Figure 59: GoPro BOM.

Nose Cone Avionics Bay

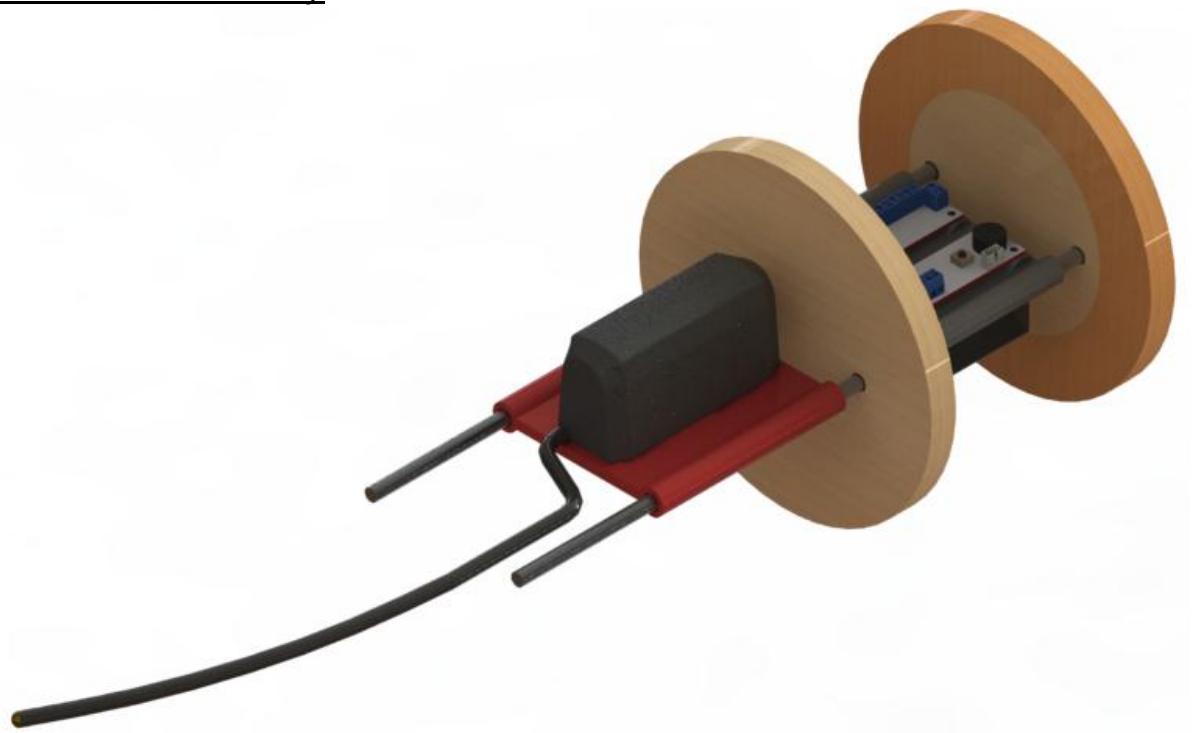


Figure 60: Rendering of nose cone avionics bay.

The nose cone avionics bay consists of two sleds that will both reside in the nose cone. The forward most sled houses a Garmin Astro DC 40 GPS dog collar which will be used to track the vehicle section. This sled will be held in place via aluminum threaded rods similar to all other avionics bays. Beneath the GPS sled will be a wooden bulkplate which will be covered with aluminum tape to shield the altimeters from the GPS signal.

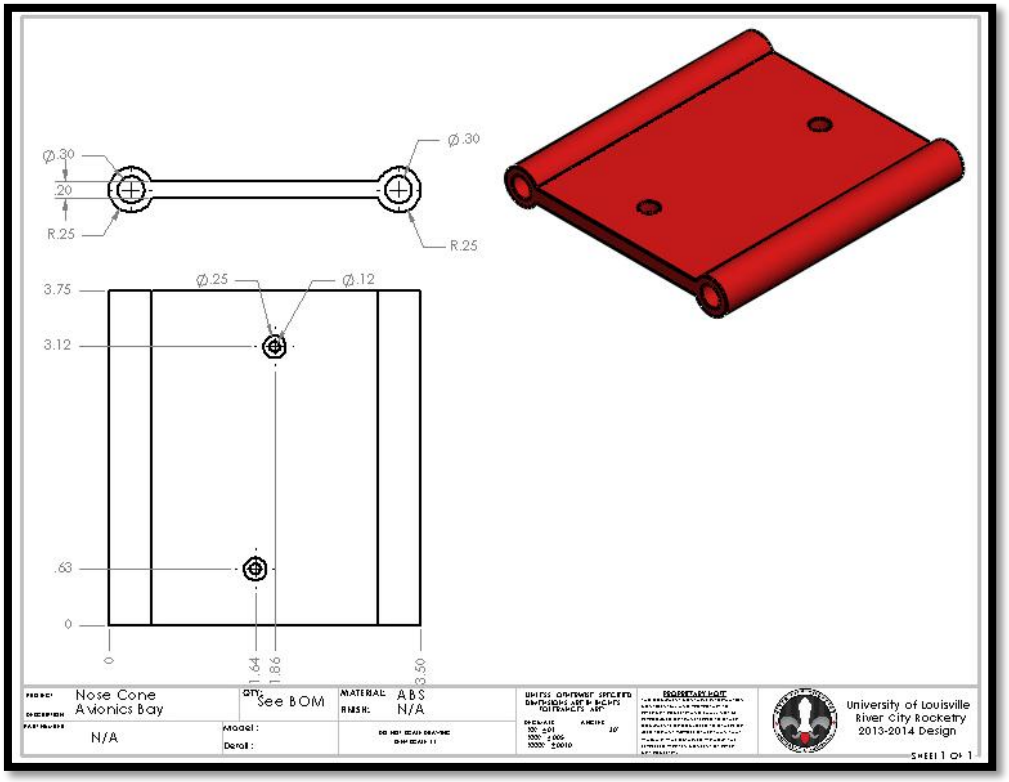


Figure 61: Nose Cone GPS sled.

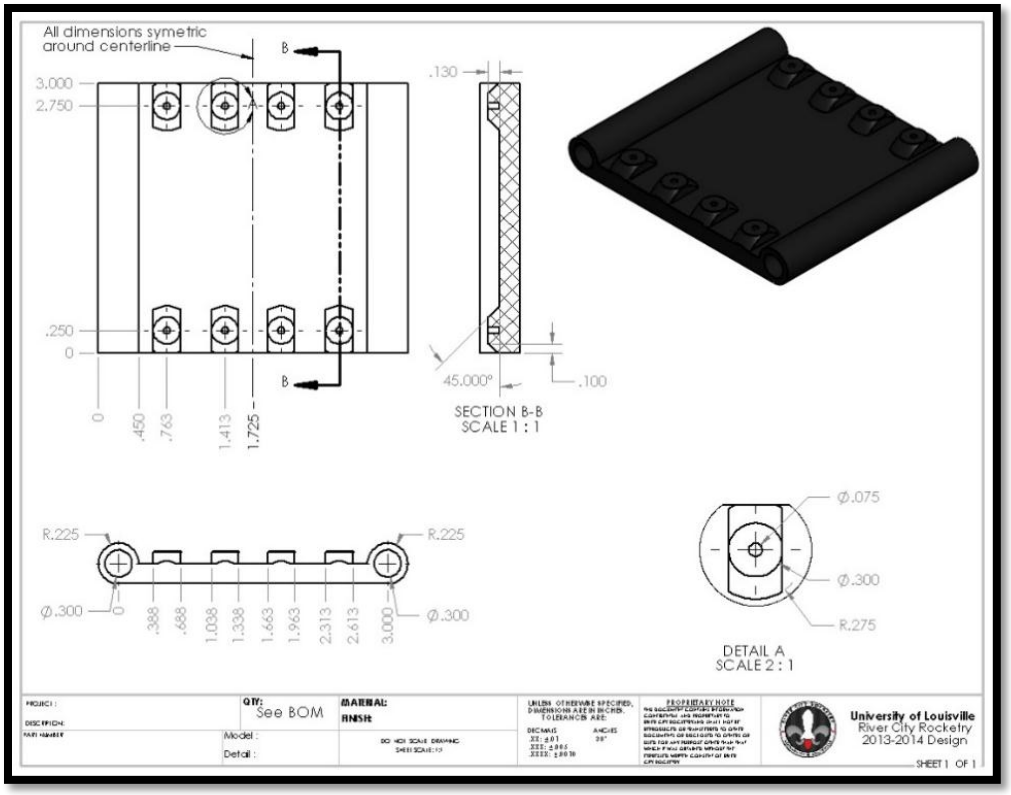


Figure 62: Nose cone Stratologger sled.

ITEM NO.	PART NUMBER	QTY.
1	Nose Cone Stratologger Sled	1
2	Nose Cone GPS Sled	1
3	Nosecone_Tip_Assembly	1
4	Stratologger	2
5	Astro Tracker	1
6	Threaded Rod	2
7	Nose Cone Centering Ring	1
8	Nose Cone Bulkhead	1
9	Nose Cone Separator Plate	1
10	Battery Holster Assembly	2

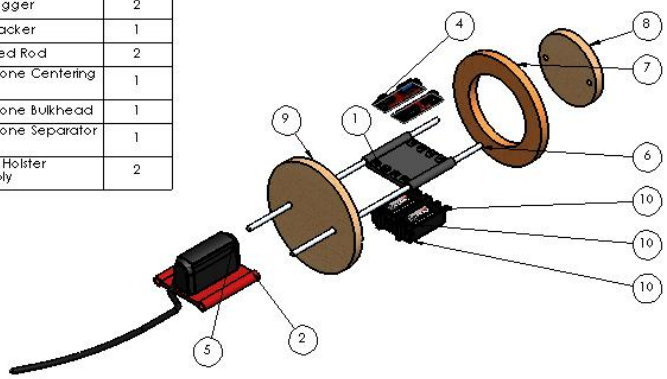


Figure 63: Nose cone altimeter and GPS BOM.

Requirement	Verification
The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The altimeters used in the booster and lower sustainer are housed in separate rocket sections and shielded by aluminum tape. The altimeters housed in the nose cone will have aluminum shielding on half of the sled to shield it from the corresponding GPS unit.
Each arming switch shall be capable of being locked in the ON position.	Key switches will be permanently screwed in through threaded holes in the witness ring of the avionics bays.
Each altimeter shall have a dedicated power supply.	A dedicated 9 volt battery will be placed on the altimeter sled for each altimeter.
The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Each recovery altimeter section will have two of the same altimeter. The nose cone will utilize Featherweight Ravens for apogee detection, the rest will contain PerfectFlite Stratologgers for altitude ejection.

Table 13. Altimeter bay verification.

Kinetic Energy

During descent the kinetic energy of the vehicle will vary depending on which parachute is currently deployed and what parachutes are yet to be deployed. The kinetic energy is determined via

$$E = \frac{mV^2}{2g_c} \tag{26}$$

where m is the total recovery mass, V is the descent velocity, and g_c is the dimensional constant. The descent velocity is calculated using equation 2. The kinetic energy at landing is shown in Table 5 and the kinetic energy for the vehicle during the lower sustainer ejection and rover ejection are shown in Table 14.

Event	Vehicle Mass (lbs)	Descent Velocity (ft/s)	Kinetic Energy (ft-lbf)
Lower Sustainer Ejection	38.2	26.11	404.52
Rover Ejection	20.2	18.99	113.11

Table 14: Event kinetic energy.

Test Results

Drag Characteristics

The drag coefficient for the circular annular parachute is listed as a range, to accurately size the parachutes the drag characteristics have to be known for various fluid conditions and the effect on construction techniques will have on the drag of the parachute. To accomplish this a test parachute was constructed that had a five foot nominal diameter. This parachute was then towed behind a vehicle, Figure 64: Drag testing.shows the hook-up to the test vehicle.

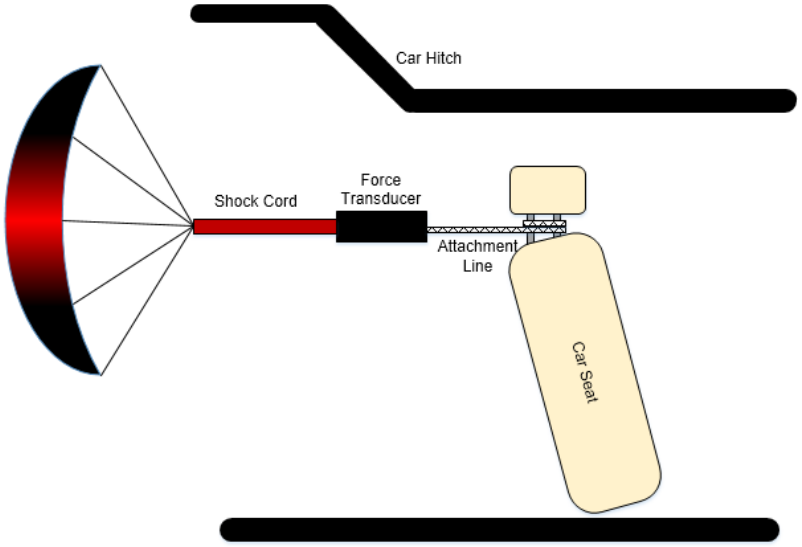


Figure 64: Drag testing.

To avoid forebody wake effects the amount of shock cord will be five times the width of the vehicle before the length of the suspension lines. The resulting force will be measured with a force transducer, a second seat (not shown for clarity) will allow a passenger to easily read the results of the device. These values will then be used to calculate the drag coefficient according to

$$C_d = \frac{2F_d}{\rho A V^2} \tag{27}$$

where F_d is the measured force, ρ is the density of the fluid, V is the fluid velocity relative to the parachute, and A is the reference area. To measure the fluid velocity a flow anemometer was used in conjunction with the test vehicle so that the effects of the wind could be accounted for without wasting trial runs. The resulting average values are shown in Table 15.

F	V	Cd
114	10.91	1.1903

Table 15: Results from drag testing.

References

1. *Knacke, T.W. Parachute Recovery Systems Design Manual. 1st edition. 1. Santa Barbara, California: Para Publishing, 1992. 5-3. Print.*
2. *Knacke, T.W. Parachute Recovery Systems Design Manual. 1st edition. 1. Santa Barbara, California: Para Publishing, 1992. 5-3. Print.*
3. *Knacke, T.W. Parachute Recovery Systems Design Manual. 1st edition. 1. Santa Barbara, California: Para Publishing, 1992. 5-3. Print.*

MISSION PERFORMANCE PREDICTIONS

Mission Performance Criteria

The following criteria must be satisfied for the mission to be considered a success.

1. The vehicle and hazard detection payload must be reusable.
2. The apogee altitude be at 10,000 feet or less.
3. A horizontal drift must be less than 1.5 miles if the alternate launch site is to be used.
4. The vehicle must have a stability margin greater than 1.75 while the booster is active and a stability margin greater than 1.3 for the sustainer.

Vehicle Characteristics

A combination of OpenRocket, solid modeling, and weighing of component parts a simulation has been made and shown in .Figure 65.

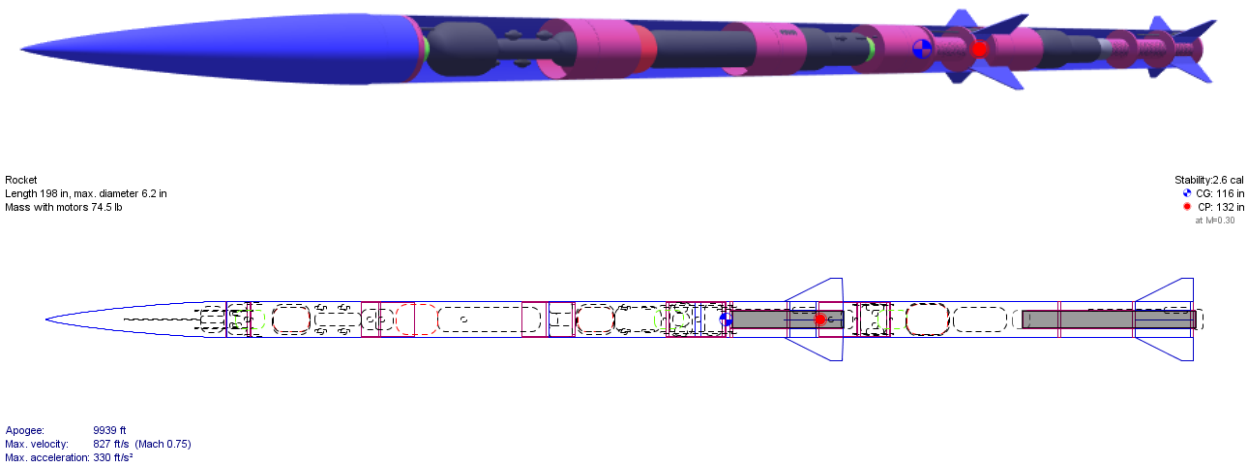


Figure 65: OpenRocket simulation

Overall Length (inches)	198
Overall Mass (lbs)	74.5
Stability Margin Both Stages	2.6
Stability Margin Single Stage	1.36

Figure 66: Vehicle dimensions.

Motor Thrust Curves

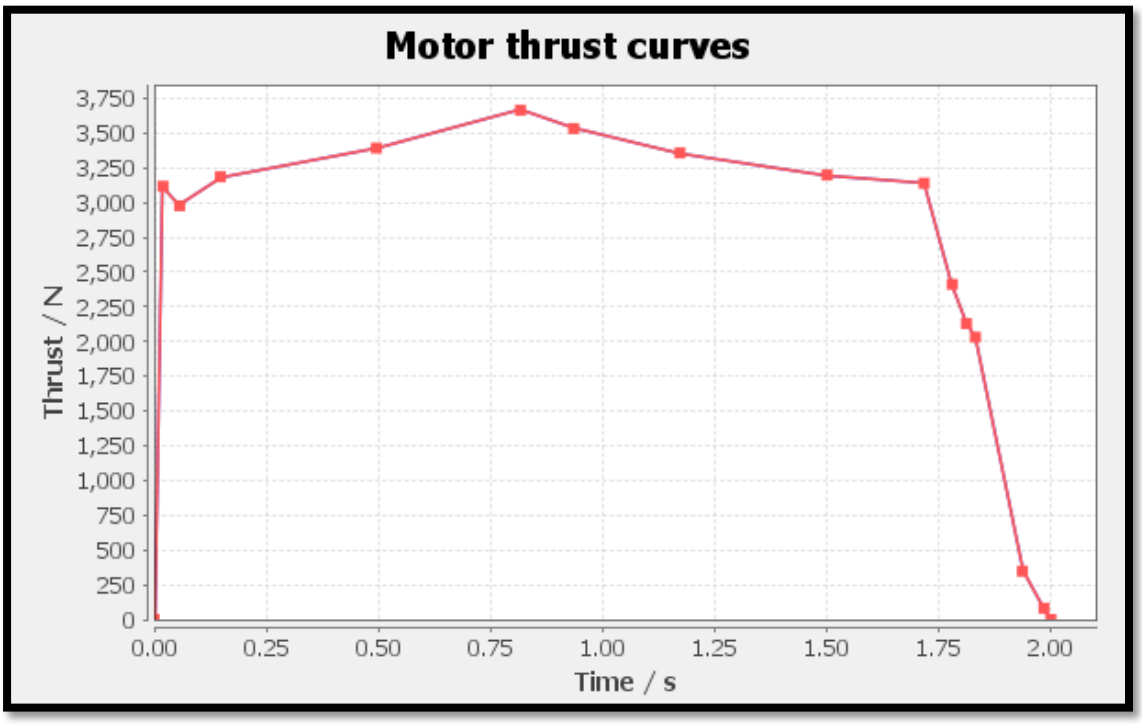


Figure 67: Thrust curve of the M3100 motor to be used in the booster.

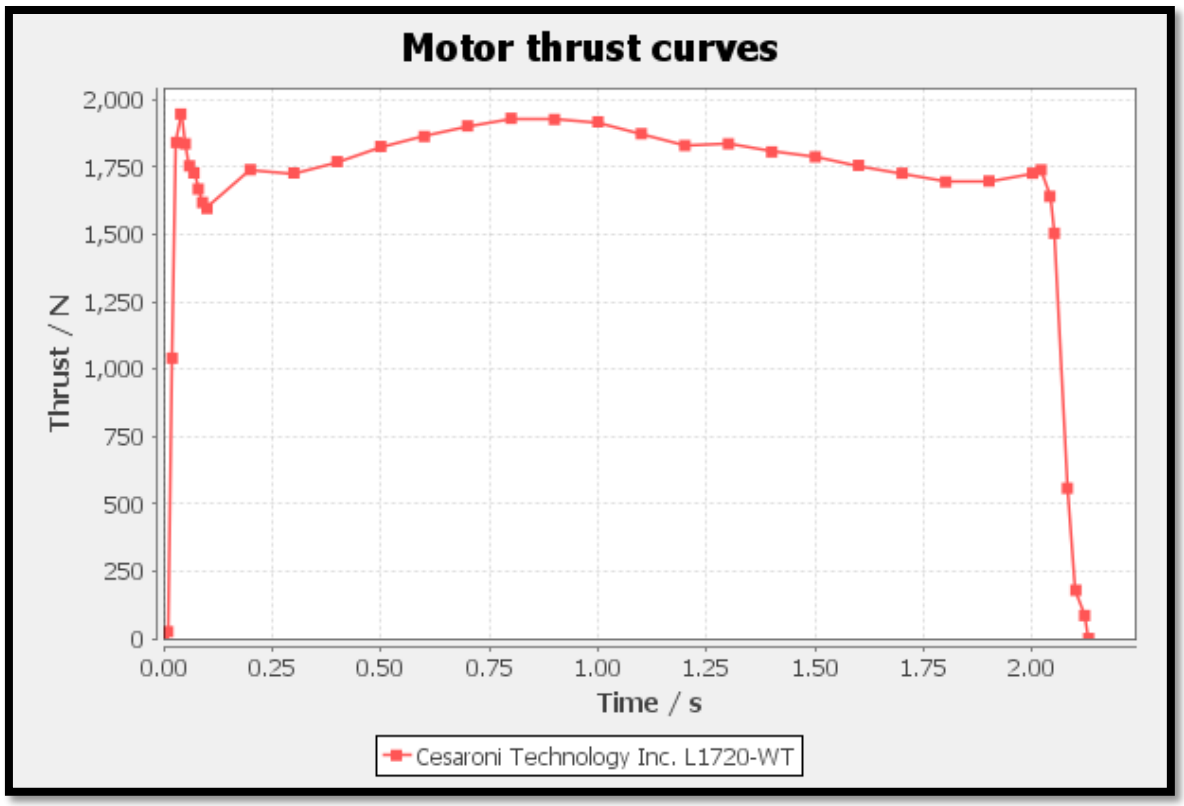


Figure 68: L1720 Thrust Curve

Stability Margin

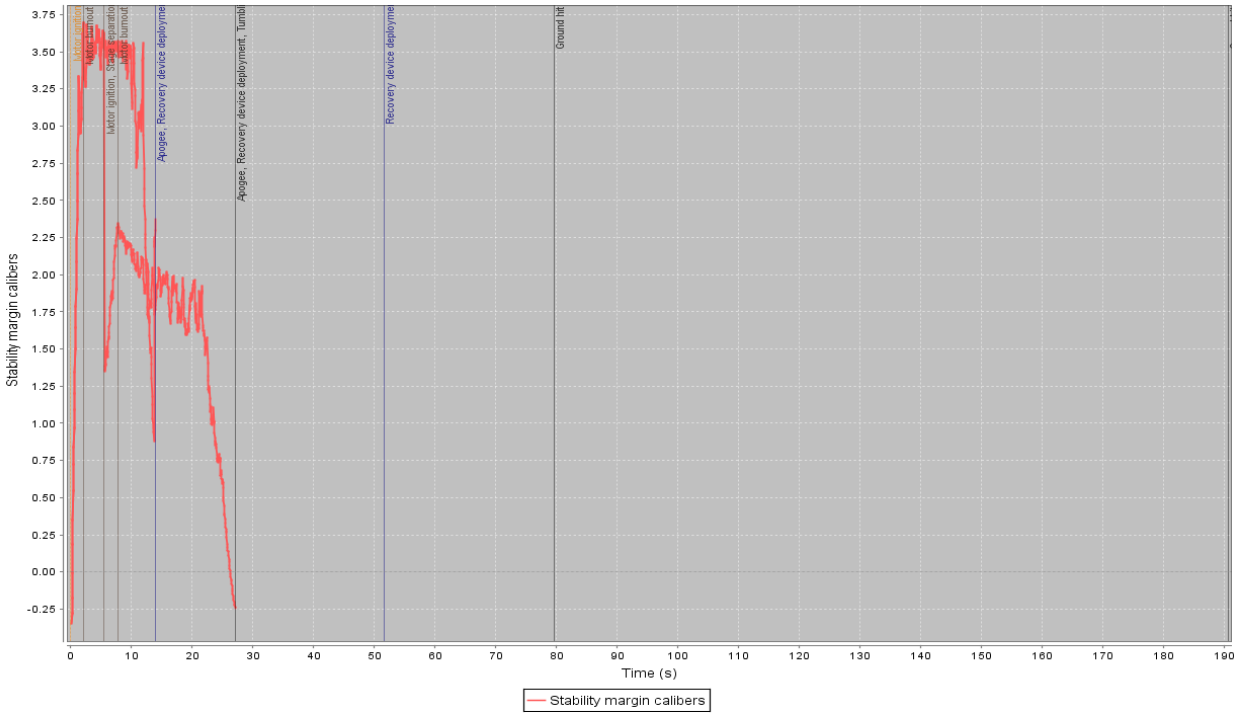


Figure 69: Stability margin.

Drag Characteristics

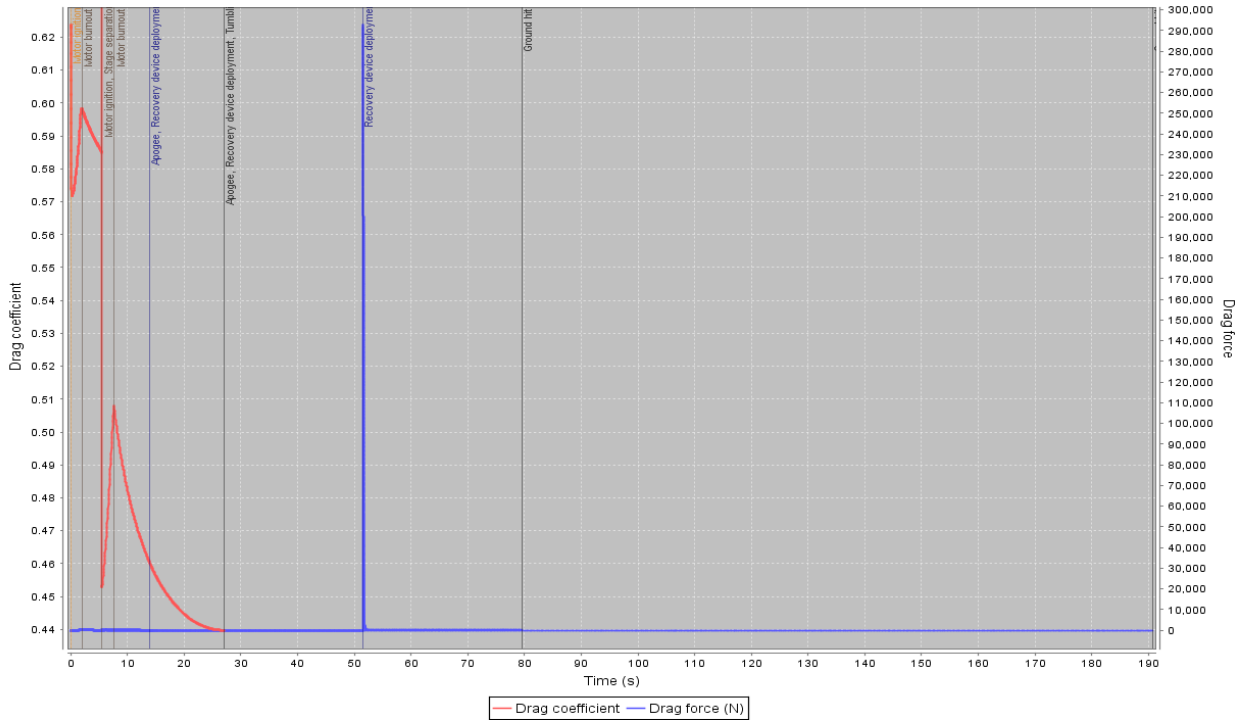


Figure 70: Drag force and drag coefficient

Drift Calculations

The total drift is calculated using by

$$Drift = D_A + D_D \tag{28}$$

where D_A is the ascent drift and D_D is the descent drift. Ascent drift is determined using the OpenRocket simulation and shown in Table 16, upwind drift is defined to be negative and downwind is defined to be positive.

Wind Speed (mph)	5	10	15	20
Booster Drift (ft.)	-40	-74	-66	-49
Sustainer Drift (ft.)	-380	-742	-1242	-718

Table 16: Ascent drift.

Descent drift was calculated using

$$D_D = V_W t \tag{29}$$

where t is the descent time, and V_w is the wind speed. The descent time was calculated using

$$t = \frac{\Delta H}{V_t} \tag{30}$$

where ΔH is the net altitude difference and V_t is the steady state velocity under parachute. The steady state velocity was calculated using

$$V_t = \sqrt{\frac{2mg}{\rho C_d A}} \tag{31}$$

Due to the nature of the recovery scheme the steady state velocity will be different not only for each section but for different altitudes because the values for A and m will be different. To account for this the process was repeated with the different sections over different altitudes to determine the total descent time. The resulting total descent drifts are shown in Table 17.

Wind Speed (mph)	5	10	15	20
Booster Drift (ft.)	766	1531	2297	3063
Lower Sustainer Drift (ft.)	2072	4144	6216	8288
Upper Sustainer Drift (ft.)	1827	3653	5480	7306
Rover Drift (ft.)	1772	3543	5315	7086

Table 17: Total descent drift.

The total drift is then calculated using equation (28), the results are shown in Table 18

Wind Speed (mph)	Drift (ft.)			
	Booster	Lower Sustainer	Rover	Upper Sustainer
5	726	1692	1392	1447
10	1457	3402	2801	2911
15	2231	4974	4073	4238
20	3014	7570	6368	6588

Table 18: Total vehicle drift.

The highest drift would still be within the 1.5 mile radius of the alternate launch site.

PAYLOAD INTEGRATION

One of the primary objectives of the team was to develop a system that would complement the hazard detection payload. By designing a rover that would integrate the hazard detection payload on it the team will be able to further simulate a real life application of the overall systems. While utilizing the hazard detection system to detect and plot out hazards in the environment, the rover would be able to interpret that data and move about an autonomous course of action while avoiding all hazards.

A primary function of the launch vehicle is to safely deliver its payload. A custom fairing system has been developed to safely house the components of the payload, all while shielding them from the environments. The team has taken caution in designing how the payload will be secured within the fairing. By utilizing custom machined semi-firm foam boards, the team has developed a housing for the rover. This housing fully encompasses the payload, and provides shock absorption from the harsh stresses seen during launch.

Launch Pad Design and Integration

In order to reduce friction between the launch pad and rocket during launch, a guide tower launch pad is being utilized. The idea behind the guide tower design is to eliminate the interference between the rocket and the launch pad, therefore allowing us to launch more consistently and control our altitude more effectively. Rather than using mounting lugs to attach the rocket to a guide rail as we have in the past, the guide tower design guides the rocket between four rails which do not contact the body as seen in Figure 35.

Figure 71: Launch Pad with Rocket

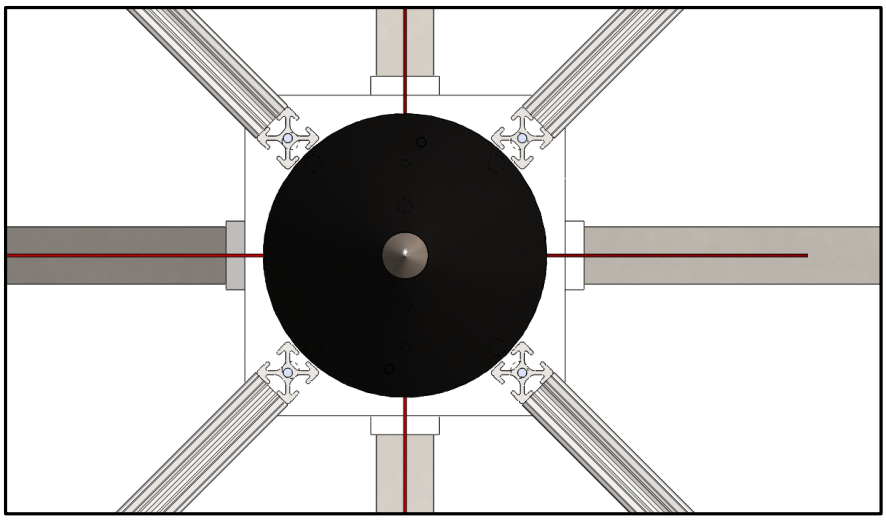


Figure 72: Top View of Rocket retained in Guide Tower.

Another added benefit of the guide tower design is the leveling adjustment. This allows for the team to accurately level the rocket before launch as well as tilt the launch pad based on local windage. Orientation of the pad is adjusted using four adjustment screws surrounding a swiveling head below the base of the guide tower as seen in Figure 37. These adjustment screws are also used to distribute the load transferred to the base during launch.

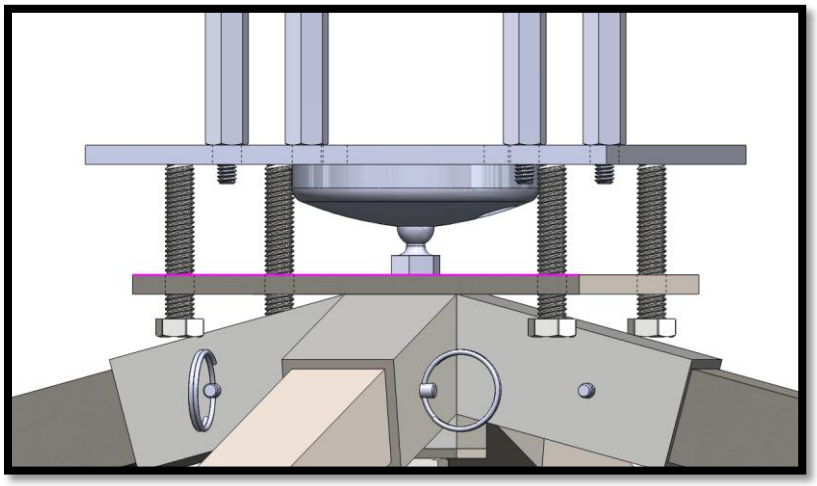


Figure 73: Leveling adjustment screws.

Also, as you can see in Figure 37, the Launch Pad Assembly can be broken apart for transport. It is designed to break down into 3 sections for transport as shown in Figure 38. These sections are assembled before launch using quick release pins and screws.

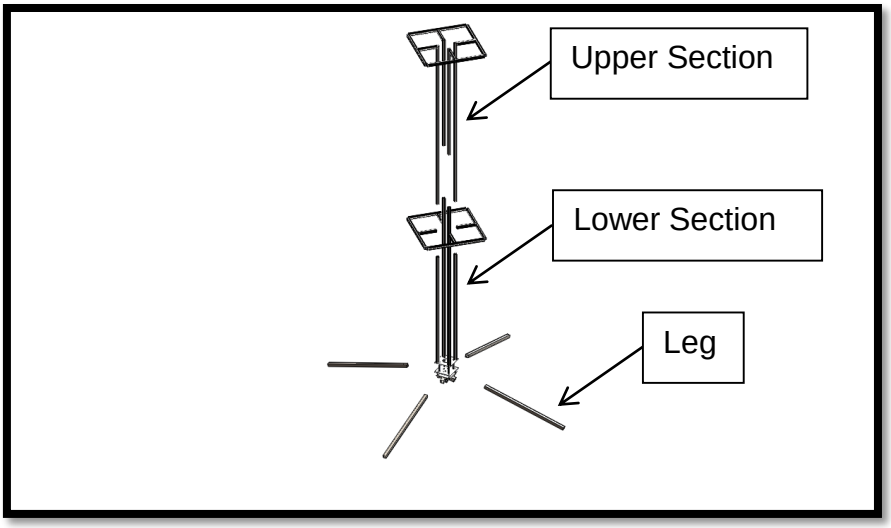


Figure 74: Break down of Launch Pad.

LAUNCH CONCERNS AND OPERATION PROCEDURES

Safety Checklist: Stability and Propulsion

To be checked and initialed by S&P Safety representative.

Stability and Propulsion Representative Signatures:

1. _____ *2.* _____

Booster Propulsion Bay Assembly Checklist (PBA):

Required Equipment:

- *75mm Casing*
- *Cesaroni M3100-WT*
- *Aeropack 75mm flanged*
- *Propulsion Bay Stand*

1. ___ The team mentor will be responsible for preparing motor within casing.
2. ___ Slide motor casing fully into the motor mount tube.
3. ___ Attach motor retention ring. Do not over-torque.
4. ___ Set completely assembled bay on stand; do not rest on fins.

Sustainer Propulsion Bay Assembly Checklist (PBA): To be checked and initialed by S&P Safety representative.

Required Equipment:

- *75mm Casing*
- *Cesaroni L1720-WT*
- *Aeropack 75mm flanged*
- *Propulsion Bay Stand*

1. ___ The team mentor will be responsible for preparing motor within casing.
2. ___ Slide motor casing fully into the motor mount tube.
3. ___ Attach motor retention ring. Do not over-torque.
4. ___ Set completely assembled bay on stand; do not rest on fins.

Safety Checklist: Hazard Detection Payload

To be checked and initialed by Payload Safety representative.

Hazard Payload Assembly:

Payload Safety Representative Signatures:

1. _____ *2.* _____

Required Equipment:

- *Payload Smartphone with SIM card*
- *BeagleBone Black*
- *Logitech C920 Webcam*
- *2S 2200mAh LiPo Battery*
- *3S 2200mAh LiPo Battery*
- *Parachute Cam*
- *Servo*
- *GPS/GPRS Cape*
- *GPS & GPRS Antennas*
- *Custom PCB*
- *2x ESCs*
- *2x Motors*
- *2x Motor Clamps*
- *Rover Body*
- *Smartphone Charger*
- *LiPo Battery Charger*
- *BeagleBone USB Cable*
- *Mini/small Phillips screwdriver*
- *Pliers*
- *Volt Meter*
- *Toolbox with extra components*

Prior to leaving for launch site:

1. ___ Ensure Lithium Polymer batteries are fully charged
2. ___ Ensure Smartphone is fully charged
3. ___ Go to T-Mobile website and enable/purchase single day call & text service for smart phone ($3/day plan)
4. ___ Turn on Smartphone and make call to activate SIM card
5. ___ Turn off Smartphone and remove SIM card
6. ___ Install SIM card onto GPS/GPRS cape
7. ___ Ensure all libraries are installed and configured on the BeagleBoard.
    a. Libraries
        i. ___OpenCV
        ii. ___SciPy
        iii. ___NumPy

iv. ___GPRS libraries [see the GPRS unit's user manual for installation instructions]
    1. ppp [Point-to-Point Protocol]
v. ___Adafruit-beaglebone-io-python [used to control the parachute release servo]
vi. ___Ensure the revision from Feb. 7th, 2014 is installed and configured. Library revisions are at https://github.com/adafruit/adafruit-beaglebone-io-python/commits/master Installation guide is at http://learn.adafruit.com/setting-up-io-python-library-on-beaglebone-black/

8. ___ Configuration
    a. ___GPRS unit
        i. ___Firmware [section 7.1 in the user manual]
        ii. ___Ensure HDMI is disabled in the file /boot/uEnv.txt. [see section 4 in the user manual]
        iii. ___Ensure the GPRS unit is set up to send data in the 850MHz+1900MHz band. See email from Duarte Carona on Feb 3, 2014. See also 3.5.7.1.56 of the GPRS AT command list.
    b. ___Payload program
    c. ___Does our systemd service point to the correct path of the startup program? See the field ExecStart in /etc/systemd/system/<programName>.service
    d. ___Confirm that the startup script is executable. chmod +x it if not.
    e. ___Confirm that the startup script actually runs on startup, without error.
9. ___ Ensure the payload starts without errors.
    a. If an error occurs, decide if we should abort launch or continue.
10. ___ Verify that the ground station device is:
    a. ___Fully charged (or at least mostly charged).
    b. ___Turned on.
    c. ___Receives text messages from a member's phone.
11. ___Verify that the web server is:
    a. ___Running.
    b. ___Accepting FTP uploads.

At launch site:

1. ___ Insure that SIM card is inserted into GPS/GPRS Cape
2. ___ Screw BeagleBone into electronics platform
3. ___ Attach Cape and Custom PCB onto BeagleBone

4. ____Verify that the GPS antenna and GPRS antenna are:
    a. ___Screwed securely into the GPS/GPRS cape.
    b. ___Secured in place with electrical tape.

5. ___ Insure that both boards are secure
6. ___ Place C-clamps around motors
7. ___ Screw C-clamps onto end plate of rover
8. ___ Attach motor's shaft to coupler using grub screws
9. ___ Insure motors are secure
10. ___ Attach ESCs to electronics platform by using metal cover
11. ___ Assemble Parachute Cam
12. ___ Attach servo to Parachute Cam
13. ___ Screw Parachute Cam assembly to electronics platform
14. ___ Insure Parachute Cam is secure
15. ___ Screw webcam to electronics platform
16. ___ Attach LiPo batteries to electronics platform using metal cover
17. ___ Attach antennas to GPS/GPRS Cape
18. ___ Wire all components to BeagleBone including batteries
19. ___ Insure that boot-up program detects no errors
20. ___ If errors occurred, solve problems
21. ____ Once boot-up program indicates no errors, attach parachute to pin on the Parachute Cam
22. ____ Inspect rover to insure all components are securely mounted
23. ____ Insert Rover into Fairing
24. ____ Say Good-bye
25. ____ Start tracking GPS coordinates for the rover

Post-flight Inspection:

1. ___ Verify all components are still attached to rover and undamaged
    a. ___ Camera
    b. ___ 2 LiPos
    c. ___ BeagleBone and attached Capes
    d. ___ Parachute Cam System
    e. ___ 2 ESCs
    f. ___ 2 Motors
2. ___ Verify Data is saved on Webserver
3. ___ Go over data acquired

Safety Checklist: Recovery

To be checked and initialed by Recovery Safety representatives.

Recovery Representative Signatures:

1. _____ *2.* _____

Prior to leaving for launch site:

Booster Parachute (BP):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*
- *Booster parachute deployment bag*
- *Swivels*

1. ___ Parachute canopy is laid out flat.
2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
3. ___ Shroud lines are taut and evenly spaced.
4. ___ Fold parachute.
5. ___ Place folded chute into deployment bag.
6. ___ Secure deployment flaps using shroud line and rubber bands.

Lower Sustainer Parachute (LSP):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*
- *Booster parachute deployment bag*
- *Swivels*

1. ___ Parachute canopy is laid out flat.
2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
3. ___ Shroud lines are taut and evenly spaced.
4. ___ Fold parachute.
5. ___ Place folded chute into deployment bag.
6. ___ Secure deployment flaps using shroud line and rubber bands.

Upper Sustainer Parachute (USP):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*

- *Booster parachute deployment bag*
- *Swivels*

1. ___ Parachute canopy is laid out flat.
2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
3. ___ Shroud lines are taut and evenly spaced.
4. ___ Fold parachute.
5. ___ Place folded chute into deployment bag.
6. ___ Secure deployment flaps using shroud line and rubber bands.

Rover Parachute (RP):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*
- *Booster parachute deployment bag*
- *Swivels*

7. ___ Parachute canopy is laid out flat.
8. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
9. ___ Shroud lines are taut and evenly spaced.
10. ___ Fold parachute.
11. ___ Place folded chute into deployment bag.
12. ___ Secure deployment flaps using shroud line and rubber bands.

Pilot Parachute 1(PP1):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*
- *Booster parachute deployment bag*
- *Swivels*

1. ___ Parachute canopy is laid out flat.

2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
3. ___ Shroud lines are taut and evenly spaced.
4. ___ Fold parachute.
5. ___ Place folded chute into deployment bag.
6. ___ Secure deployment flaps using shroud line and rubber bands.

Pilot Parachute 2 (PP2):

Required Equipment:

- *Rubber bands*
- *Hook*
- *Clamp*
- *Booster parachute deployment bag*
- *Swivels*

1. ___ Parachute canopy is laid out flat.
2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.
3. ___ Shroud lines are taut and evenly spaced.
4. ___ Fold parachute.
5. ___ Place folded chute into deployment bag.
6. ___ Secure deployment flaps using shroud line and rubber bands.
7. ___ Fold shock chord.

Booster Altimeter Bay:

Required Equipment:

- *Standard flathead screwdriver*

1. ___ Verify altimeters are properly programed.
2. ___ Screw altimeters into sled.
3. ___ Attach 9V battery to sled.

Lower Fairing Altimeter Bay:

Required Equipment:

- *Standard flathead screwdriver*

1. ___ Verify altimeters are properly programed.
2. ___ Screw altimeters into sled.
3. ___ Attach 9V battery to sled.
4. ___ Screw titometer into sled.

Nosecone Altimeter Bay:

Required Equipment:

- *Standard flathead screwdriver*

1. ___ Verify altimeters are properly programed.
2. ___ Screw altimeters into altimeter sled.
3. ___ Attach 9V battery to altimeter sled.
4. ___ Attach GPS to GPS sled.
5. ___ Install threaded rods into bulkhead.
6. ___ Attach sled through threaded rods.
7. ___ Attach upper bulkhead.
8. ___ Attach GPS sled.
9. ____ Check GPS for full charge.

Launch day procedures

Booster Parachute Assembly (BPA):

Required Equipment:

- *Nomex*

1. ___ Verify motor hardware is attached.
2. ___ Attach longest length of shock chord to motor hardware.
3. ___ Verify motor is installed.
4. ___ Attach other end of shock chord to parachute.
5. ___ Attach shock chord that attached to parachute to the u bolt.
6. ___ Attach pilot parachute to top of deployment bag.
7. ___ Remove all rubber bands.
8. ___ Wrap deployment bag in Nomex.
9. ___ Insert both parachutes into booster.

Lower Sustainer Parachute Assembly (LSPA):

Required Equipment:

- *Nomex*

1. ___ Attach parachute to avionics bay.
2. ___ Remove all rubber bands.
3. ___ Wrap deployment bag in Nomex,
4. ___ Insert parachute into airframe.

Rover Parachute Assembly (RPA):

1. ___ Attach rover parachute deployment bag to upper bulk plate.
2. ___ Remove all rubber bands.
3. ___ Fit parachute into foam insert.
4. ___ Attach shroud lines to rover.

Fairing Parachute Assembly (FPA):

Required Equipment:

- *Nomex*

1. ___ Attach parachute to u bolt on upper bulk plate.
2. ___ Attach parachute to fairing.
3. ___ Attach pilot parachute to deployment bag.
4. ___ Remove all rubber bands.

5. ___ Wrap deployment bag in Nomex,
6. ___ Insert parachute into airframe.

Booster Altimeter Bay:

Required Equipment:

- *Multimeter*
- *Precision flathead screwdriver*

1. ___ Verify battery has charge greater than 5V.
2. ___ Verify proper shielding.
3. ___ Plug in battery to altimeter.
4. ___ Plug altimeters into terminal blocks.
5. ___ Verify correct charge is to correct block.
6. ___ Install altimeter bay into airframe.

Lower Fairing Altimeter Bay:

Required Equipment:

- *Multimeter*
- *Precision flathead screwdriver*

1. ___ Verify battery has charge greater than 5V.
2. ___ Verify proper shielding.
3. ___ Plug in battery to altimeter.
4. ___ Plug altimeters into terminal blocks.
5. ___ Verify correct charge is to correct block.
6. ___ Install altimeter bay into airframe.

Nosecone Altimeter Bay:

Required Equipment:

- *Precision flathead screwdriver*
- *Standard flathead screwdriver*

1. ___ Verify battery has charge greater than 5V.
2. ___ Verify proper shielding.
3. ___ Plug in battery to altimeter.
4. ___ Plug altimeters into terminal blocks.
5. ___ Verify correct charge is to correct block.
6. ___ Install nosecone altimeter bay to the nose cone.

Safety Checklist: Fairing Payload

To be checked and initialed by Fairing Payload Safety representatives.

Fairing Payload Representative Signatures:

1. _____ *2.* _____

Prior to leaving for launch site:

Maintenance (MT):

Required Equipment:

- *Wrench sets*
- *Wire strippers*
- *Wire cutters*
- *Screwdrivers*
- *Extra wiring*
- *Extra batteries*
- *Extra hardware*

Required PPE:

- *Safety glasses*

1. ___ Inspect that all hardware components have duplicates in their own labeled bags.
2. ___ Ensure all proper wrenches and screwdrivers needed for hardware are secured into toolbox.

Altimeter Housing (AH):

Required Equipment:

- *Altimeter box*
- *StratoLogger*
- *9V battery*
- *Screw switch*
- *Multimeter*

1. ___ Ensure the black powder is properly sealed from moisture and secured in the team's explosives box.
2. ___ Test StratoLogger's to ensure functionality is nominal.
3. ___ Test screw switch to ensure connections are nominal.
4. ___ Verify batteries have a voltage of at least 5V.

Pyro Cap Assembly (PCA):

Required Equipment:

- *Hardware*
- *O-ring*
- *Black powder*
- *Electronic matches*

Required PPE:

- *Nitrile gloves*

1. ___ Check O-ring for deformities or cracks
2. ___ Inspect shells for bends, or wear that would cause clearance conflicts
3. ___ Inspect electronic matches for burnt out matches
4. ___ Check that black powder is sealed and has no exposure to moisture.

Fairing Deployment Mechanism (FDM):

Required Equipment:

- *Hardware*
- *Excess shock cord*

1. ___ Inspect that springs have not been warped and still retain their proper spring rate.
2. ___ Ensure that the hinge is free of debris and opens smoothly.

Fairing Assembly (FA):

1. ___ Check that the airframe is not deformed.
2. ___ Check the structural integrity of all bulk plates.
3. ___ Inspect the foam inserts and ensure there is no play or deformations in them.
4. ___ Ensure that the fairing can smoothly open and close.

Launch day procedures

Fairing Payload Assembly (FPA):

Required Equipment:

- *Black powder*
- *StratoLoggers*
- *9V Batteries*
- *Screw switches*
- *Electronic matches*
- *Springs*
- *Hinge*
- *Square U-Bolts*
- *Rover payload*
- *4-40 Shear Pins*
- *Duct tape*

1. ___ Lay out the two halves of the fairing and ensure that all permanent components are still intact and flight ready.
2. ___ Install both StratoLoggers.
3. ___ Install both screw switches.
4. ___ Secure both 9V batteries.
5. ___ Wire up both altimeter housing assemblies.
6. ___ Ensure the screw switch is not activated, and wire in all electronic matches.
7. ___ Install acrylic faceplates to altimeter housings.
8. ___ Install hinge to one half of the fairing.
9. ___ Place springs and one section of shock cord on one square U-bolt.
10. ___ Install square U-bolt with springs attached.
11. ___ Join the two halves together by installing the other half of the hinge to the second half of the fairing.
12. ___ Place other end of springs on secondary square U-bolt along with the other section of shock cord.
13. ___ Install secondary U-bolt.
14. ___ Securely place rover payload and rover recovery system into the foam inserts.
15. ___ Tie the nylon cord from the deployment bag to the appropriate eyebolt.
16. ___ Insert and tape electronic matches into proper ports in pyro cap.
17. ___ Install O-ring into O-ring groove around the pyro cap.
18. ___ Fill both black powder chambers with black powder.
19. ___ Close the fairing.
20. ___ Carefully install the pyro cap so that no black powder spills.
21. ___ Install 4-40 shear pins into the pyro cap assembly.
22. ___ Tie nylon cord from the pyro cap's eyebolt to the appropriate eyebolt in the adjacent bulkplate.

Safety Checklist: Launch Pad

Launch Pad Assembly Checklist (LPA): To be checked and initialed by Launch Pad Safety representative.

Launch Pad Safety Representative Signatures:

1. _____ *2.* _____

Required Equipment:

- *Allen Wrench Set – Standard*
- *Upper and Lower Launch Pad sections*
- *Launch Pad legs*
- *9/16" Wrench*
- *Leg quick release pins*
- *3/4" wrench*
- *Hammer*
- *Stakes*
- *Clamp*
- *Drill*

1. ___ Inspect launch pad for any cracked welds.
2. ___ Attach legs to Launch pad using quick release pins.
3. ___ Polish mounting pins on lower launch pad section.
4. ___ Slide Upper Launch Pad section onto corresponding mounting pins in the Lower Launch Pad section.
5. ___ Secure brackets to upper and lower launch pad.
6. ___ Position lower Launch Pad enclosure so that it is fastened to both upper and lower sections of the launch pad.
7. ___ Secure lower launch pad enclosure to guide rails using existing hardware.
8. ___ Tighten all 4 leveling screws so that the base is stationary. Be careful not to over torque.
9. ___ Slide assembled rocket into guide rails and check for clearance. If clearance is not sufficient troubleshooting may be necessary.
10. ___ Upright Launch Pad and level the guide rails using leveling screws. Be sure all screws are tight.
11. ___ Drill four holes in ground for tensioning lines.
12. ___ Stake down tensioning lines using stakes.
13. ___ Fine tune adjustments for tensioning lines using turnbuckles.

Safety Checklist: General Procedures and Before/After Launch

Overall Body Assembly Checklist (OBA): To be checked by Safety Officer upon completion of all sub-team assemblies.

Safety Officer Signatures:

1. _____ *2.* _____

Required Equipment:

- *Allen Wrench Set – SAE*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *Socket Wrench Set for ¼-20 Nuts*
- *Polishing Cloth*
- *Masking tape*

1. ___ Insert and secure SMD bay into the lower airframe. Ensure that all viewing and vent ports are aligned correctly.
2. ___ Insert and secure Recovery bay on top of the SMD bay. Align rod holes and run the rods down until they engage with the transition plate. Attack corresponding ¼-20 nuts to the rods at the transition plate end.
3. ___ Secure down the corresponding ¼-20 nuts. Do not over-torque.
4. ___ Attach all parachutes and shock cables to bulkhead. See Recovery Checklist on proper parachute folding techniques.
5. ___ Attach upper airframe to the bays and secure into place with corresponding bolts.
6. ___ Insert properly folded parachute and deployment bad into bay. Ensure no entanglement with shock lines occurs.
7. ___ Organize and insert shock cables and drogue into upper airframe.
8. ___ Align nose cone with shear pin holes and insert into upper airframe.
9. ___ Insert shear pins into holes utilizing a small, flat-head screw driver. Ensure that all shear pins are tight fitting and will not fall out during ascent.
10. ___ Attach completely assembled propulsion bay to completely assembled transition bay. The acrylic transfer will have to couple with the propulsion bay properly to be seated.
11. ___ Clean transition section of any debris from assembly operations.
12. ___ Tape motor igniter to the outside of the propulsion bay in a place easily seen by the field RSO.
13. ___ A final visual inspection will need to be done to ensure all systems are go.

At Launch Pad Checklist (ALP): To be checked by Safety Officer upon completion of Overall Body Assembly and Launch Pad Assembly.

Safety Officer Signature: _____

Launch Team Signatures: All signatures must be included for a "Go" at launch.

Stability and Propulsion Representative: _____

Recovery Payload Representative: _____

Electronics Representative: _____

Launch Pad Representative: _____

Team Captain: _____

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *Propulsion Bay Stand*
- *Magnetic Switch Magnet*
- *Switch Rods*
- *GoPro camera*

1. ___ Verify flight card has been properly filled out and permission has been granted by RSO to launch.
2. ___Place rocket on launch pad.
3. ___ Tilt and rotate the launch pad in desired direction, or in direction ruled necessary by RSO.
4. ___ Secure all launch pad tie downs.
5. ___ Ensure proper connection has been made with ground station electronics.
6. ___ Arm all altimeters (priority one), cameras, and payloads. Check for correct LED readout, beeping pattern, etc.
7. ___ Remove igniter, separate leads, and run up into motor until igniter is fully seated. Attach yellow plastic cap and run igniter out of the provided hole. Form a loop in the igniter to keep it fully seated within the motor.
8. ___ Tap ignition system leads together to remove any static buildup that could cause ignition. Wrap igniter leads around each clip. Drape the ignition system leads out of the direct path of the exhaust.
9. ___ Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
10. ___ Arm launch pad camera and begin recording.

11. ___ Clear launch pad area and do not return until range has been reopened by the RSO.

Safety Checklist: During and After Flight (DAF):

Flight Timer Signature: _____

First Event Observer Signature: _____ Time: _____

Second Event Observer Signature: _____ Time: _____

Landing Event Observer Signature: _____ Time: _____

Ground Station Operator Signature: _____

Video Recorder Signature: _____

Rapid Retrieval Team Member #1: _____

Rapid Retrieval Team Member #2: _____

Rapid Retrieval Team Member #3: _____

Required Equipment:

- *Stopwatch or phone timer.*
- *Magnetic Switch Magnets*

1. Rapid Retrieval team members are to be within close vicinity to a vehicle ready to move within a few seconds notice.
2. Start stopwatch upon liftoff and call out time in 5 second intervals until T-10 seconds until first event. Continue to call out times until T-10 seconds to second event.
3. Maintain line of sight with rocket at all times. Indicate any observed anomalies out loud to alert spectators.
4. While retrieving rocket, disarm all rocket recovery systems first.
5. Before disturbing the rocket, note any damages and anomalies with root causes. Document these for later examination.
6. Disassemble the rocket looking for any signs of wear, damage, or fatigue. Note what repairs will have to be made, if any.

After Flight Checklist: To be checked and initialed by Recovery Safety representative.

Recovery Representative Signatures:

1. _____ *2.* _____

1. ___ Inspect all shroud lines for any damage, or burn marks.
2. ___ Inspect all shroud attachment points for damage.
3. ___ Inspect entire canopy for any damage, or stretching.
4. ___ Inspect deployment bag for damage.

Damage found on shroud lines? Y / N

*Notes:*_____

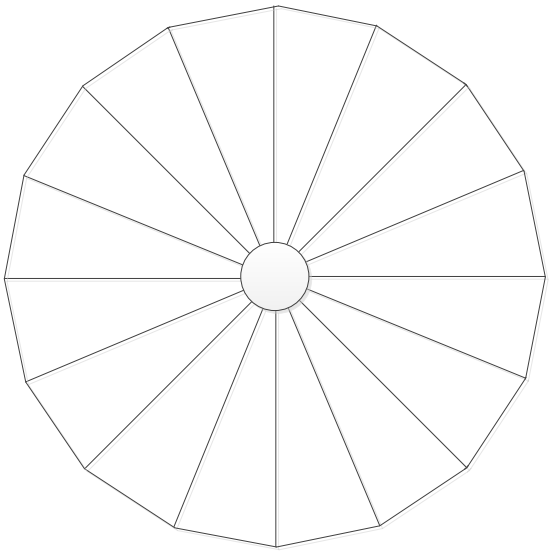
Damage found on attachment points? Y / N

*Notes:*_____

Damage found on deployment bag? Y / N

*Notes:*_____

Mark area where tearing or stretching was found on canopy



Damage **Notes:**

_____

_____

_____

Repair Plan:

_____

_____

_____

Altitude Achieved: _____

Motor Used: _____

Location: _____

Temperature: _____

Pressure: _____

Wind Speed: _____

Event #1 Success: Y or N

Event #2 Success: Y or N

Captain Approval: 1. _____

2. _____

SAFETY AND ENVIRONMENT (VEHICLE)

SAFETY PLAN

Safety Officer Responsibilities

The safety officer for the River City Rocketry team during the 2013-2014 season is Emily. She is responsible for ensuring the overall safety of the team, students, and the public as well as compliance with all laws and regulations. The following are the Safety Officer's specific responsibilities.

- Establish and brief the team on a safety plan for various environments, actions, and materials used.
- Remain active in the design, construction, testing, and flight of the rocket in order to quickly identify any new safety hazards and to ensure the team complies with the team safety plan.
- Identify safety violations and take appropriate action to mitigate the hazard.
- Enforce proper use of Personal Protective Equipment (PPE) during construction, testing and flights of the rocket.
- Make MSDS sheets and operator manuals available and easily accessible to the team at all times.
- Provide plan for proper purchase, storing, transporting, and use of both motors and energetic devices.
- Ensure compliance with all local, state, and federal laws.
- Ensure compliance with all NAR regulations
- Provide a written team safety manual that includes hazards, safety plans and procedures, PPE requirements, MSDS sheets, operator manuals, FAA laws and NAR regulations.
- Confirm that all team members have red and comply with all regulations set forth by the team safety manual.
- Ensure the safety of all participants in educational outreach activities, providing PPE as necessary.

Emily has written a team safety manual that each team member was required to review and sign indicating compliance. The document includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, and NAR regulations. The manual will be revised throughout the year as a need arises. Emily has confirmed that each team member has read and acknowledged the safety manual and will continue to enforce all statements in the safety manual. The manual can be found on the team website along with a signed document of compliance from each team member.

Hazard Analysis

Risk Assessment Matrix

By methodically examining each human interaction, environment, rocket system and component, hazards have been identified and will continue to be brought to the team's attention. Each hazard has been assigned a risk level through the use of a risk assessment matrix, found in Table 21, by evaluating the severity of the hazard and the probability that the hazard will occur.

A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, damage to the rocket and/or damage to equipment. This criteria is outlined below in Table 19.

Severity		
Description	**Value**	**Criteria**
Catastrophic	1	Could result in death, significant irreversible environmental effects, complete mission failure, monetary loss of $5k or more.
Critical	2	Could result in severe injuries, significant reversible environmental effects, partial mission failure, monetary loss of $500 or more but less than $5k.
Marginal	3	Could result in minor injuries, moderate environmental effects, complete failure of non-mission critical system, monetary loss of $100 or more but less than $500.
Negligible	4	Could result in insignificant injuries, minor environmental effects, partial failure of non-mission critical system, monetary loss of less than $100.

Table 19: Severity Criteria

A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. The probability value was determined for each hazard based on an estimated percentage chance that the mishap will occur given the following:

- All personnel involved have undergone proper training on the equipment being used or processes being performed.
- All personnel have read and acknowledged that they have a clear understanding of all rules and regulations set forth by the latest version of the safety manual.
- Personal Protective Equipment is used as indicated by the safety lab manual and MSDS.
- All procedures were correctly followed during construction of the rocket, testing, pre-launch preparations, and the launch.

- All components were thoroughly inspected for damage or fatigue prior to any test or launch.

The criteria for the selection of the probability value is outlined below in Table 20.

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.
Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 20: Probability Criteria

Through the combination of the severity value and probability value, an appropriate risk level has been assigned using the risk assessment matrix found in Table 21. The matrix identifies each combination of severity and probability values as either a high, moderate, or low risk. The team's goal is to have every hazard to a low risk level by the time of the competition launch. Those that are not currently at a low risk level will be brought down through redesign, new safety regulations, or any other measures seen fit to reduce risk. Risk levels will also be reduced through verification of systems.

Risk Assessment Matrix				
Probability Value	**Severity Value**			
	Catastrophic-(1)	Critical-(2)	Marginal-(3)	Negligible-(4)
Almost Certain- (1)	2-High	3-High	4-Moderate	5-Moderate
Likely-(2)	3-High	4-Moderate	5-Moderate	6-Low
Moderate-(3)	4-Moderate	5-Moderate	6-Low	7-Low
Unlikely-(4)	5-Moderate	6-Low	7-Low	8-Low
Improbable-(5)	6-Low	7-Low	8-Low	9-Low

Table 21: Risk Assessment Matrix

Lab and Machine Shop Risk Assessment

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 22 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Risk Assessment
The hazards outlined in Table 23 are risks linked to the launch pad that the team has previously designed and built. Since the launch pad was used throughout the entirety of last season without any problems, we are confident in the safety of its design.

Stability and Propulsion Risk Assessment
The hazards outlined in Table 24 are risks associated with stability and propulsion. There are particular risks involved when staging a rocket. This year is the team's first experience attempting a complex rocket. The risks were initially higher than would be considered acceptable for the competition launch. Sub-scale tests have verified that the team can successfully launch a dual stage rocket successfully. The risks will be reduced at a later date to reflect our confidence in the system when it can be validated that the full scale rocket can be staged successfully. The planned full scale testing will reassure that the designed system is safe and operates as intended.

Recovery Risk Assessment
The hazards outlined in Table 25 are risks associated with the recovery. Since there are four recovery systems onboard, many of the failure modes and results will apply to all of the systems but will be stated only once for conciseness.

Vehicle Assembly Risk Assessment
The hazards outlined in Table 26 are risks that could potentially be encountered throughout the assembly phase and during launch preparation.

Environmental Hazards to Rocket Risk Assessment
The hazards outlined in Table 27 are risks from the environment that could affect the rocket or a component of the rocket. Several of these hazards resulted in a moderate risk level and will remain that way for the remainder of the season. These hazards are the exception for needing to achieve a low risk level. This is because several of these hazards are out of the team's control, such as the weather. The hazards that the team can control will be mitigated to attain a low risk level.
Hazards to Environment Risk Assessment
The hazards outlined in Table 28 are risks that construction, testing or launching of the rocket can pose to the environment.

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	1. Improper training on power tools and other lab equipment.	1a. Mild to severe cuts or burns to personnel. 1b. Damage to rocket or components of the rocket. 1c. Damage to equipment	2	4	Low	1. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. 1. Safety glasses must be worn at all times. 1. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool.	1a. Mild to severe rash. 1b. Irritated eyes, nose or throat with the potential to aggravate asthma. 2. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	3	3	Low	1a. Long sleeves should be worn at all times when sanding or grinding materials. 1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required. 2. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.
Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical spills	1. Chemical splash. 2. Chemical fumes.	1. Mild to severe burns on skin or eyes. 2. Lung damage or asthma aggravation due to inhalation of fumes.	2	4	Low	MSDS documents will be readily available at all times and should be thoroughly reviewed prior to working with any chemical. 1. Nitrile gloves shall be used when handling hazardous materials. 1. Personnel are familiar with locations of safety features such as an eye wash station.

						1. Safety goggle are to be worn at all times when handling chemicals. 2. When working with chemicals producing fumes, appropriate precautions should be taken such as working in a well-ventilated area, vapor masks, fume hood.
Damage to equipment while soldering	1. Soldering iron is too hot 2. Prolonged contact with heated iron	The equipment could become unusable. If parts of the payload circuit get damaged, they could become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and the team is experienced in soldering. The soldering iron will be set the correct temperature 2. For temperature sensitive components we can use the sockets to solder our ICs to.
Dangerous fumes while soldering	1. Use of leaded solder can produce toxic fumes 2. Leaving soldering iron too long on plastic could cause plastic to melt producing toxic fumes.	Team members could become sick due to inhalation of toxic fumes. Irritation could also occur.	3	3	Low	1. The team will use well ventilated areas while soldering. Fans will be used. 2. The soldering iron will only be on parts for the recommended amount of time.
Potential burns to team members while soldering	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be encouraged to follow all safety protocols related to soldering.

Overcurrent from power source while testing	Failure to correctly regulate power to circuits during testing	Team members could suffer electrical shocks which could cause burns to heart arrhythmia	2	4	Low	The circuits will be analyzed before they are powered to insure they don't pull too much power. Power supplies will also be set to the correct levels.

Table 22: Lab and Machine Shop Risk Assessment

Launch Pad Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Unstable launch tower	Un-level ground or improperly staked launch tower.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch.
Unleveled launch pad	Un-level ground or improperly leveled launch tower.	The launch tower could tip over during launch, making the flight of the rocket unpredictable.	1	5	Low	The launch pad should always be placed on a level surface. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR.
Cracked weld on launch pad	Fatigue and over stressing during transportation.	The launch tower could potentially become unstable.	3	4	Low	The launch tower should be inspected prior to each use for any cracked welds. Launch tower is to be kept clean in order to be able to identify any cracks.
Sharp edges on the launch pad	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	4	3	Low	Sharp edges of the launch pad should be filed down and de-burred.
Brush fire caused by rocket during launch	Dry launching conditions.	Small brush fire.	4	3	Low	Wait until the range safety officer has cleared personnel to

						approach the launch pad and extinguish any fires that have been started. The launch tower also has a blast deflector to prevent brush fires.

Table 23: Launch Pad Risk Assessment

Stability and Propulsion Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Motor fails to ignite.	1. Faulty motor. 2. Delayed ignition. 3. Faulty e-match. 4. Disconnected e-match.	1,3,4. Rocket will not launch. 2. Rocket fires at an unexpected time.	3	4	Low	Follow NAR safety code and wait a minimum of 60 before approaching the rocket to ensure that the motor is not simply delayed in launching. If there is no activity after 60 seconds, have the safety officer check the ignition system for a lost connection or a bad igniter. If this does not fix the failure mode, be prepared to remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare.
Motor explodes on the launch pad.	Faulty motor	Rocket and interior components significantly damaged.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR in order to ensure that no one is hurt by flying debris. Extinguish any fires that may have been started when it is safe to approach. Collect all debris to eliminate any hazards created due to explosion.

Rocket doesn't reach high enough velocity before leaving the launch pad.	1. Rocket is too heavy. 2. Motor impulse is too low. 3. High friction coefficient between rocket and launch tower.	1,2. Unstable launch.	1	5	Low	Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in graphite prior to each launch in order to minimize friction. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.
Booster does not separate from rocket.	1. High angle of flight. 2. Too tight of fit between the booster and sustainer.	1. Booster motor will not fire. 2. Damage to interior components of the booster section.	3	4	Low	1. A tiltometer will be placed in the rocket to determine the angle of flight. If the angle of flight is too high, the sustainer motor will not fire and the rocket will fully recover. 2. The coupling between the booster and sustainer will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight.
Sustainer ignites early.	False reading from the altimeter.	Significant damage to the booster section, particularly in the case of burns to the booster recovery system. Would also result in loss of overall	3	4	Low	Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. Should altimeters continue to fail, a redesign would need to be evaluated to ensure proper ignition.

		altitude achieved.				
Sustainer does not ignite	1. Altimeter malfunction. 2. Tiltometer malfunction. 3. Faulty igniter or igniter becomes dislodged.	1,2,3. Sustainer motor will not fire and the rocket will achieve an altitude significantly below the goal. Rocket will still fully recover.	1	4	Moderate	1. Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. 2. The tiltometer will not allow the sustainer to ignite at an angle greater than 40°. Tiltometer will be significantly tested prior to use to ensure it allows the signal to ignite the motor within the allowable range. The tiltometer will be zeroed on the launch pad prior to each use. 3. There will be 2 igniters used for redundancy.
Sustainer ignition delayed	1. Altimeter malfunction. 2. Bad connection between ignition control systems.	If the delay allows for the rocket to fall past parallel to the ground, significant damage would be done to the rocket and personnel could be at risk. If it is a short delay, causing the rocket to fall less than 90°, there will be a loss in altitude.	1	4	Moderate	1. Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. Raven diagnostic codes will alert personnel if there is an error. 2. All connections are to be inspected prior to flight. This inspection is included as a part of launch day procedures.

Fins shear during flight	Insufficient adhesion during installation resulting in a failure in the epoxy.	Unstable rocket, causing the flight path to become unpredictable.	1	5	Low	Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. Examine external epoxy beads for cracks prior to launch.
Airframe buckles during flight	Airframe encounters stresses higher than the material can support.	Rocket will become unstable and unsafe during flight.	1	5	Low	Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated.
Internal bulkheads fail during flight	Forces encountered are greater than the bulkheads can support.	1. Internal components supported by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.	1	5	Low	The bulkheads will be designed to withstand the force from the motor firing with an acceptable factor of safety. 1. Electrical components could be damaged and will not operate as intended during flight. 2. A catastrophic failure is likely. A portion of the rocket or the fairing would become ballistic.

Table 24: Stability and Propulsion Risk Assessment

Recovery Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket does not split to allow for recovery system deployment.	1. Not enough pressurization to break shear pins. 2. Coupling has too tight of fit.	1,2. Rocket follows ballistic path, becoming unsafe.	1	5	Low	1. The separation section of the rocket will be designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. 2. The coupling between the sections will be sanded down to have a loose fit, preventing the

						two sections from getting stuck together during flight. If separation does not occur, the rocket will follow a ballistic path, becoming unsafe. All personnel at the launch field will be notified immediately.
Altimeter or e-match failure	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this failure mode. Should all altimeters or e-matches fail, the recovery system will not deploy and the rocket will become ballistic, becoming unsafe. All personnel at the launch field will be notified immediately.
Parachute does not open	1. Parachute gets stuck in the deployment bag. 2. Parachute lines become tangled.	1,2. Rocket follows ballistic path, becoming unsafe.	1	4	Moderate	Deployment bags will be specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design.
Rocket descends too slowly	Parachute is improperly sized.	The rocket will drift farther than	3	3	Low	The parachutes have each been carefully selected and designed to

		intended, potentially facing damaging environmental obstacles.				safely recover its particular section of the rocket. Should this be too large, the parachute will have to be resized.
Parachute has a tear or ripped seam	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful inspection prior to packing each parachute, this failure mode should be eliminated.
Parachute or chords become burnt	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful packing and the appropriate use of Nomax material, this failure mode is unlikely.
Recovery system separates from the rocket	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to become ballistic.	1	5	Low	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.

Table 25: Recovery Risk Assessment

Vehicle Assembly Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**

Rocket drop (INERT)	Mishandling of the rocket during transportation.	Minimal damage and scratches to components of the rocket.	4	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.
Rocket drop (LIVE)	Mishandling of the rocket during transportation.	1. Minimal damage and scratches to components of the rocket if no charges go off. 2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.
Black powder charges go off prematurely	1. Altimeters send a false reading. 2. Open flame sets off charge.	1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	All electronics will be kept in their OFF state for as long as possible during preparation. Open flames and other heat sources will be prohibited in the area.
Seized nut or bolt due to galling or cross threading	Repetitive uninstalling and reinstalling of parts made of	Component becomes unusable, potentially	2	4	Low	Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated.

	materials prone to galling.	ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized.				

Table 26: Vehicle Assembly Risk Assessment

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.
Rain	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage.
High winds	N/A	1. Have to launch at high angle, reducing altitude achieved.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the

		2. Increased drifting. 3. Unable to launch.				entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the salt flats being extremely soft, as well as local launch sites, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.

Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.

Table 27: Environmental Hazards to Rocket Risk Assessment

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, work their way into humans, causing illness.	4	3	Low	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any OSHA standards.
Destruction of salt flats.	Staking of the launch tower in hard ground.	Holes will have to be drilled in the salt flats in order to properly stake the launch tower.	4	1	Moderate	Due to the nature of the location of the competition launch, holes will have to be drilled into the salt flats in order to stake the launch pad. This has been discussed with personnel at the site and they have verified that this is acceptable to do.

Table 28: Hazards to Environment Risk Assessment

NAR/TRA PROCEDURES

NAR Safety Code

The below table describes each component of the NAR High Power Rocket Safety Code, effective August 2012, and how the team will comply with each component.

NAR Code	Compliance
1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only Darryl Hankes, Gregg, and Zak are permitted to handle the rocket motors. If during the season, an additional team member achieves the required certification, he/she will be approved to handle the motors after that date.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The Mechanical Engineering team will be responsible for selecting the appropriate materials for construction of the rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors will be purchased through Wildman Rocketry and will only be handled by certified members of the team who are responsible for understanding how to properly store and handle the motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and will wait 60 seconds after the	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.

last launch attempt before allowing anyone to approach the rocket.	
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will ensure that the launch pad meets these requirements, using any additional tools necessary on launch day to ensure compliance and a safe launch.
8. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	
9. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams and a maximum expected altitude of less than 610 meters (2000 feet).	All team launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any rocketry safety issues.
10. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will comply with this rule and any determination the Range safety Officer makes on launch day.
11. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Recovery team will be responsible for designing and constructing a safe recovery system for the rocket. A safety checklist will be used on launch day to ensure that all critical steps in preparing and packing the recovery system and all necessary components into the rocket are completed.
12. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Table 29: NAR Safety Code Compliance

TEAM SAFETY

A team safety meeting will be held prior to any construction in order to ensure that every team member is fully aware of all team safety regulations as detailed in the team safety manual which has been included in the appendix. Each team member is required to review and acknowledge the safety manual. As revisions are made and released, team members are responsible for remaining up to date with team safety regulations. The team safety manual covers the following topics:

- Lab Workshop Safety
- Material Safety
- Personal Protective Equipment regulations
- Launch Safety Procedures
- Educational Engagement Safety
- MSDS sheets
- Lab and tool specific rules.

If a violation to the contract occurs, the violator will be revoked of his or her access to the lab until having a meeting with the safety officer to review and reconfirm compliance with the safety rules.

Prior to each launch, a briefing will be held to review potential hazards and accident avoidance strategies. In order to prevent an accident, a thorough safety checklist has been created and will be reviewed on launch day. Throughout preparations, it will be the responsibility of the safety officer to confirm that each of the necessary tasks for a successful launch are completed. Two team members are required to sign off, verifying that each required task has been completed in order to ensure a safe launch.

LOCAL/STATE/FEDERAL LAW COMPLIANCE

The team has reviewed and acknowledged regulations regarding unmanned rocket launches and motor handling. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 “Code for High Power Rocket Motors” documentation will be made available to all members of the team. The previously listed documents are included in the appendix. Due to the length of Regulation 27, Part 55, a URL is given for the document.

MOTOR SAFETY

Darryl Hankes, the team mentor, who has obtained his Level 3 TRA certification, will be responsible for acquiring, storing, and handling the teams rocket motors at all times. Team members Gregg and Zak, whom are Level 2 certified, are permitted to assist in this responsibility for the sub-scale flights. The full scale motors require a Level 3 certification, so Darryl is the only person permitted to handle the competition motors. If at any time,

another member of the team acquires the appropriate certification, they will be added to the list of people permitted to handle the team's motors. By having obtained at minimum a Level 2 certification, the individual has demonstrated that he or she understands the safety guidelines regarding motors. Any certified member of the team that handles or stores the team's motors is responsible for following the appropriate measures. The motors for both test and competition launches will be transported by car to the launch site.

SAFETY COMPLIANCE AGREEMENT

The University of Louisville USLI team understands and will abide by the following safety regulations declared by NASA. The following rules will be included in the team safety contract that all team members are required to sign in order to participate in any builds or launches with the team.

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

HAZARD DETECTION PAYLOAD CRITERIA

TESTING AND DESIGN OF PAYLOAD EXPERIMENT

Overview of Hazard Detection Payload

The purpose of the hazard detection payload is to scan the terrain for any potential landing hazards during descent. A webcam will be used to obtain images which will be analyzed via a BeagleBone Black microprocessor. An off-the-shelve Printed Circuit Board (PCB) will be mounted onto it which contains a GPS unit to track location and a GPRS phone module to transmit data to our ground station. The BeagleBone will also have a custom made PCB on top of the previous one that will contain other essential payload circuitry. Pre-existing libraries, such as OpenCV, will facilitate the creation of the team's custom hazard detection software package. The hazard payload will be mounted onto a rover that will be able to autonomously drive around once it has determined it has landed. The objectives for this payload are shown in Table 44 in the Payload Science Value section. This payload requires the team to demonstrate knowledge in embedded system design, image processing, circuit design, and CAD modeling which are all topics taught at the undergraduate level. Due to the rigorous nature of the University of Louisville's engineering program, the electronics team is able to consist of all upper-level undergraduate students.

Electronics Hardware Components

One of the main design challenges the team is facing with this payload is having enough processing power due to all the systems that must be running. To accomplish this, the team chose the BeagleBone Black which will be the brains for the entire payload. By using one microprocessor, and off-the-shelve products the payload's hardware requirements are simplified which will also make integration easier. Figure 75 shows the layout of the payload's electrical hardware excluding any power sources.

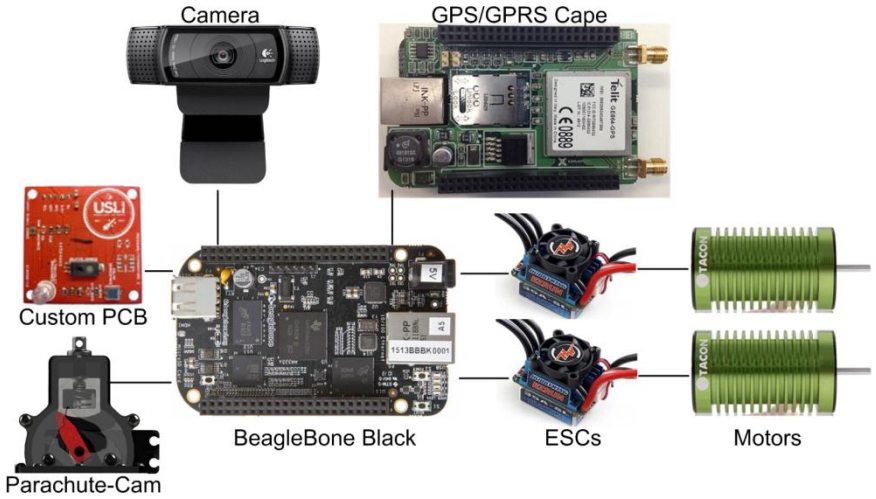


Figure 75: Electronic Hardware Layout

One of the main lessons learned from last year's competition was that cell-phones were excellent for transmitting data. Therefore, this year the team plans to keep using similar cell-phone technology by using an off the shelf circuit board that contains a GPRS module for data transmission as well as a GPS sensor. This PCB will be mounted onto a BeagleBone Black (BBB) microprocessor which will be used as the brains that will control all of the payload components. One of the many features of the BBB is its USB slot which will be used for connecting a Logitech C920 webcam directly. This allows the team to eliminate the need for additional circuitry to interface both of these components. Added to the BBB will be a custom made PCB that will contain any needed sensors to determine crucial events such as launch, apogee, and landing. This PCB will also be used for attaching the circuitry required for powering the BeagleBone, the Electronic Speed Controllers (ESC) for the rover's motors, and for the servo controlling the Marker-Cam. Each component shown in Figure 75 is described in more detail below.

BeagleBone Black

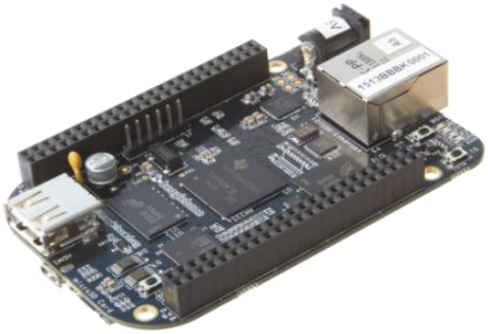


Figure 76: BeagleBone Black

As previously mentioned, the brain of the hazard-detection operation is a BeagleBone Black (BBB) which is a Linux based microprocessor. The BeagleBone is responsible for reading in data from various sensors such as the camera, performing processing on that data, and taking action accordingly. The BeagleBone has a 1GHz Sitara ARM Cortex A8 Processor with 512MB of onboard DDR3 RAM, and also comes with 2GB of storage and features a microSD card slot allowing for more storage if necessary. The BBB is capable of using I2C, SPI, UART, analog, and PWM through one of its many 65 GPIO pins. The BeagleBone also has built in USB, micro-USB, microSD card, HDMI, and Ethernet terminals. All of these options will allow us to choose a wider range of components to use on the payload.

The BeagleBone is capable of being used as a standalone computer and thus has an integrated SGX530 3D Graphics Engine that will be useful for image processing. To power the BeagleBone, only 460ma @ 5V are required. The BeagleBone weighs in at only 1.4oz with dimensions of 3.4 x 2.1 inches. The BeagleBone is also capable of handling up to four PCBs stacked on top of it without any significant performance

deterioration which will be very useful for our application. Due to the intense processing that will have to be done, the BBB is the perfect single-board computer for the hazard detection payload. Table 30 shows the requirements the board satisfies, what features will help meet that requirement, and how they will be verified.

Requirements	Features	Verification/Testing
The payload shall incorporate a camera system that scans the surface during descent in order to detect potential landing hazards.	The USB and micro-USB slots will insure a camera is able to connect directly. Video4Linux libraries are already included on the BeagleBone.	The webcam has been verified to work with the BeagleBone and we are able to obtain images via the BeagleBone.
The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if any landing hazards are present.	The 1GHz Arm Processor, and 512 MB DDR3 RAM will be capable of handling the processing involved. The 2GB onboard storage and microSD slot will allow us enough room for code and data storage.	Simple image processing has been run via the BeagleBone and data was able to be processed in a few seconds.
The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station.	The BeagleBone is capable of having 4 capes stacked upon it allowing us to use a cape with transmitting capabilities.	Data has been sent from the BeagleBone to a cell phone via SMS. Data has also been sent to a webserver.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	Low-power consumption in standby mode will allow us to keep critical components active until launch is detected.	Tests will be conducted to insure all components are active for at least 1 hour.
An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	The BeagleBone is capable of having 4 capes stacked upon it allowing us to use a cape with GPS capabilities.	The GPS coordinates from the GPS/GPRS cape have been verified to match our expected location.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The BeagleBone is a standalone computer that can function without any external circuits.	The payload is completely separate from any components relating to the recovery system.

Table 30: BeagleBone Requirement, Feature, and Verification Table

Logitech C920 HD Pro Webcam

Figure 77: Logitech C920 HD Pro Webcam

After the BeagleBone, this camera is be the most important payload component since it will be responsible for obtaining images with as high resolution possible while still being able to be processed at a decent rate. The C920 webcam is capable of taking 15 megapixel photos, as well as recording in full HD 1080p resolution. The C920 is also able to go down to 480p in case less resolution is needed so that the BeagleBone can process the images. This webcam also includes H.264 video format for better compression. The autofocus on the camera can be turned off, which will be crucial as there will be a significant amount of movement during descent and having the autofocus feature active will be a hindrance.

An advantage of using the C920 webcam is that there was already proven compatibility between it, the BeagleBone, and OpenCV (image processing software library). The camera will be connected to the BBB using the BeagleBone's on-board USB port. The C920 weighs in at 4.8oz and has an unfolded dimension of 2.8 x 7.5 x 8.9 inches. The foldable stands for the camera will also make integration onto the rover easy by allowing us to screw it onto the electronics platform. This camera retails for $70 on Amazon making it affordable. Table 31 shows the requirements the camera satisfies, what features will help meet that requirement, and how they will be verified.

Requirements	Features	Verification/Testing
The payload shall incorporate a camera system that scans the surface during descent in order to detect potential landing hazards.	15 megapixel photo capability and 1080p resolution will insure good clarity.	The webcam has been tested to work with the BeagleBone.
The data from the hazard detection camera shall be analyzed in real time by a	H.264 video compression format will allow the BeagleBone to better process the images.	The BeagleBone has been verified to work with H.264 video format.

custom designed on-board software package that shall determine if landing hazards are present.		

Table 31: C920 Webcam Requirement, Feature, and Verification Table

GPS/GPRS Cape

Figure 78: GPS/GPRS Cape

This cape is crucial to the hazard detection payload as it adds GPS and GPRS capabilities to the BeagleBone. The cape uses a Telit GE-864 module to obtain GPS coordinates. GPRS stands for General Packet Radio Service and is considered to be in between 2G and 3G networks used for cell-phones. GPRS extends the GSM capabilities of 2G data service to allow internet access, SMS messaging and broadcasting, MMS transmission, and P2P service.

Since the team has chosen to use SMS for data transmission, the features provided by this cape have been very useful. To access the GPRS capabilities of this cape, a SIM card is required so that it can connect to a cell-phone network. The SIM card from one of the phones used in last year's payload is being used to connect to the T-Mobile network as it allows for prepaid usage of $3 per day for unlimited data which makes it affordable for the team's budget. Figure 79 through Figure 82 shows that T-Mobile has coverage for each of the team's expected launch sites, including the Bonneville Salt Flats in Utah.

Since the cape uses a cell phone module, the power transmission is controlled remotely by the closest cellular base station. The station dynamically assigns a power level with the intent to maintain good signal-to-noise ratio while limiting interference, overloading, and power consumption. The Telit GE-864 GPRS module is rated for different classes which control the power levels it can be assigned by the base stations. The GPS module is also assigned an operating range called a level but this is not controlled by the base stations. The information for each of the modules onboard is shown below.

Module	Class/Level	Power (W)	Frequency (MHz)	Sensitivity (dBm)
GPRS	1	1	1800/1900	106
	4	2	850/900	107
GPS	L1	---	1572.42	163

Table 32. GPRS and GPS Frequencies, Power, and Sensitivity.

Figure 79: T-Mobile Coverage for Louisville, KY

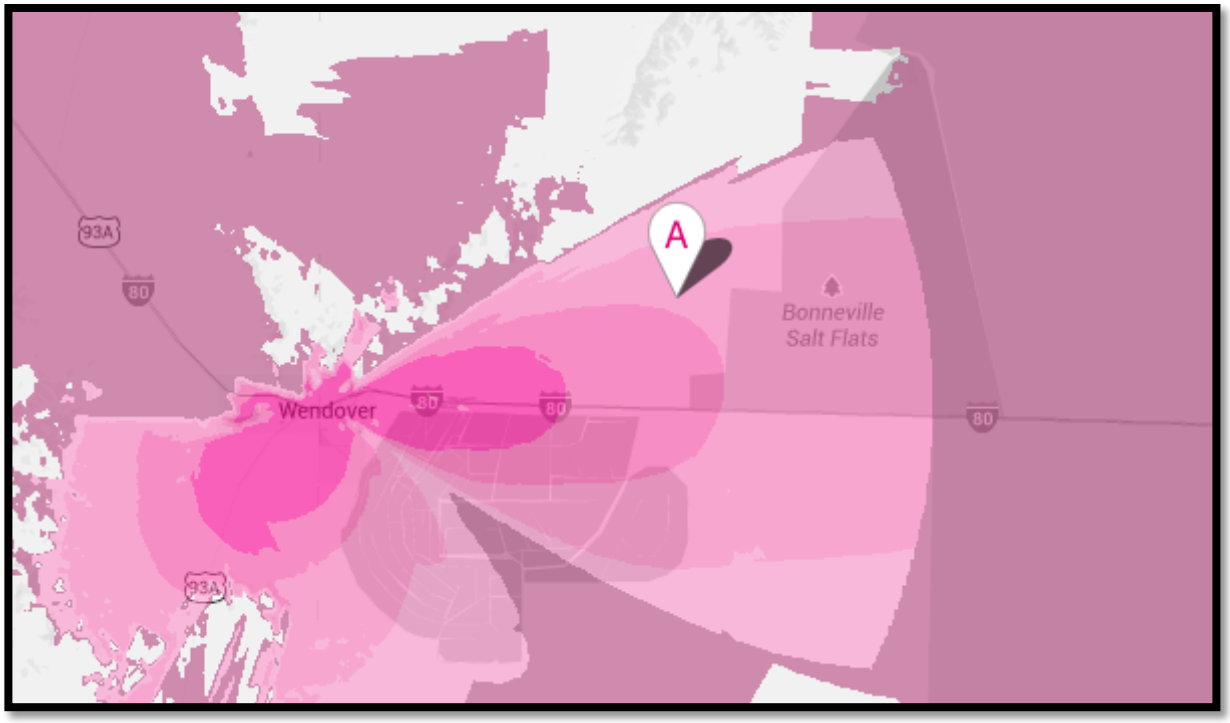


Figure 80: T-Mobile Coverage for Bonneville Salt Flats, Utah

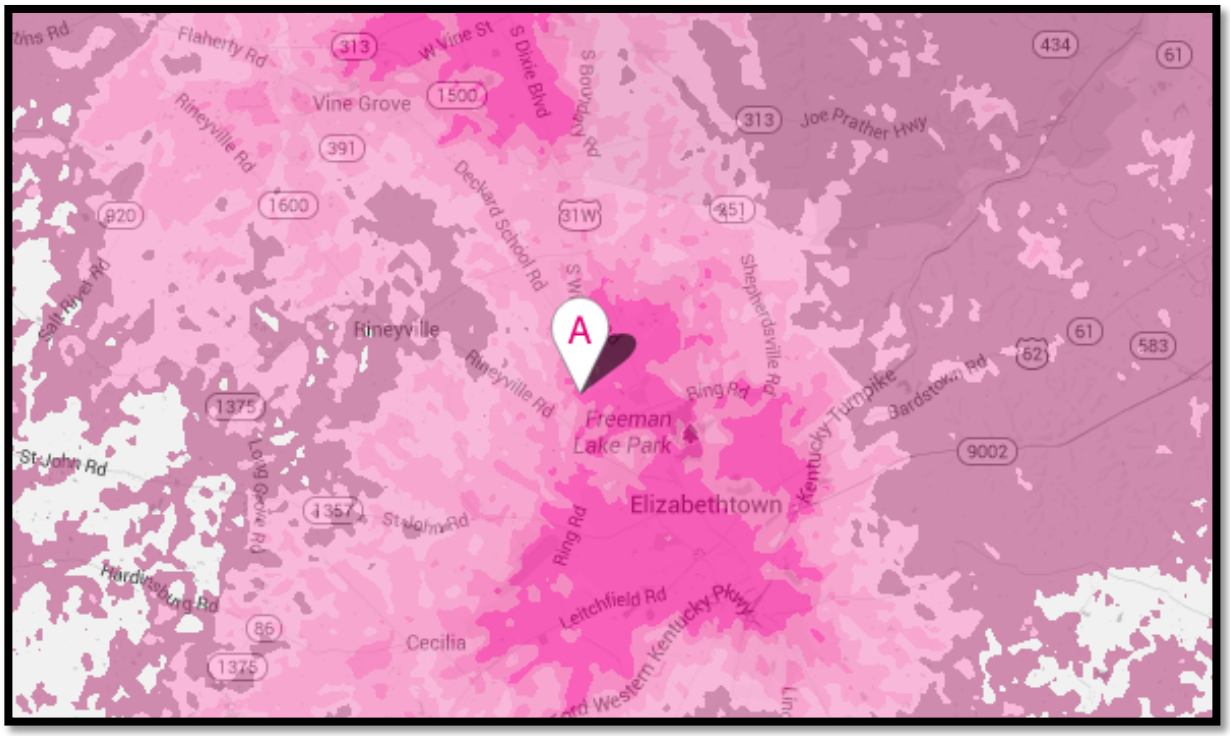


Figure 81: T-Mobile Coverage for Elizabethtown, KY

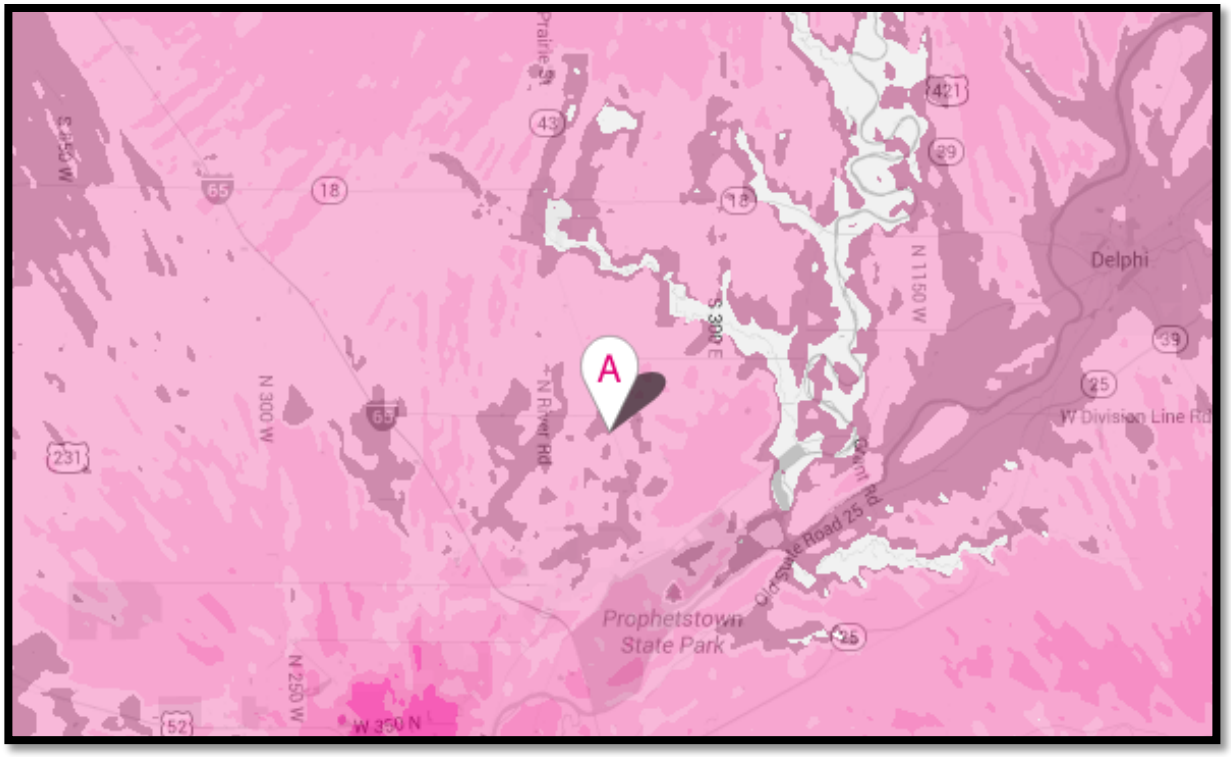


Figure 82: T-Mobile Coverage for Ash Grove, IN

The data will be transmitted from the cape to a cell phone that will act as our ground station. A continuous stream of data packets will be sent from this unit to the ground station. The content of these packets will either indicate that no hazards have been detected, or every hazard that has been detected will be listed along with the type of hazard. This cape is specifically made for the BBB so it is guaranteed to work and it attaches to the pins on the BBB via headers. Two antennas attach to the cape to allow it to receive GPS and transmit GPRS data.

Requirements	Features	Verification/Testing
The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station.	This cape features a GPRS module capable of transmitting data over SMS by using a cell phone SIM card.	Data has been sent using this cape via SMS to a cell phone.
An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	A Telit GE-864 GPS module is included on the cape. This module is accurate to less than 2.5 meters.	Google Maps has verified that the GPS co-ordinates match our location.

The electronic tracking device shall be fully functional during the official flight at the competition launch site.	This cape is compatible with the BeagleBone which will be in charge of operating the cape.	Tests will be conducted to insure the cape does not experience any problems.

Table 33: GPS/GPRS Cape Requirement, Feature, and Verification Table

HobbyWing 35A EZRUN ESC

Figure 83: HobbyWing 35A EZRUN ESC

To interface the motors on the rover with the BeagleBone, an off the shelf electronic speed controller (ESC) will be used, with one ESC used per motor. The ESC will be getting a Pulse Width Modulation (PWM) signal from a circuit on the custom PCB the team will create. This PWM signal will be used to control the speed and rotation of the motors by generating a three-phase AC signal. Controlling the ESC via the PWM circuit instead of the using code will allow the BeagleBone to concentrate on more important tasks. These ESCs have a built-in overload protection circuit and feature a small fan unit to cool down the ESC in case it overheats. A 35 amp ESC was chosen since each motor can draw up to 20A, but to protect the ESC from any sudden spikes, a higher value ESC was chosen. These ESC's are used for RC cars which enables the motor to rotate in clockwise and counterclockwise directions and will be useful for our rover application. The retail price per ESC is around $32 which is within the team's budget.

Requirements	Features	Verification/Testing
*The rover must travel at least 20 feet once it has landed.	The overload protection circuit will prevent the motors from drawing too much power from the motors. The ESC can also output the required 3-phase signal that's required to run brushless motors.	The ESCs have been verified to work with the PWM circuit and with the motors. The overload protection has also been proven to work as it would not allow higher voltages to pass that would damage the motors.

Table 34: ESC Requirement, Feature, and Verification Table

Tacon 1200KV Brushless Motors

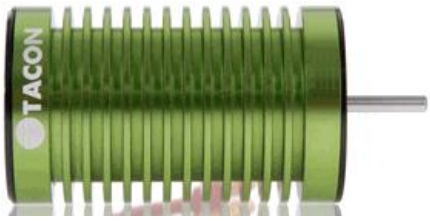


Figure 84: Tacon 1200KV Brushless Motor

The motors that will be used were mainly chosen for the torque they provide. These motors have a 1200KV rating which means they will rotate 1200 times a minute per voltage applied with no load. The motors also have 23 turns each which is another indicator of their higher torque. Their maximum voltage is 12.6V and the maximum current draw is 20A. These motors weigh 213.8 grams, are 36mm in diameter and 60mm in length. The D-shaft on the motors will allow a coupler to be used to attach a longer shaft. The reason that brushless type motors were chosen was because they require little to no maintenance, offer more torque, have better heat dissipation, and experience no power loss across brushes which means better efficiency. These motors cost $23 each which is within the team's budget.

Requirements	Features	Verification/Testing
*The rover must travel at least 20 feet once it has landed.	The 1200KV rating and high torque will allow the rover to go over most terrain in a short amount of time.	Once the rover is built, the motors will be tested to make sure they can safely drive the rover. The motors have been verified to operate with the ESCs.

Table 35: Motor Requirement, Feature, and Verification Table

Lithium Polymer Batteries

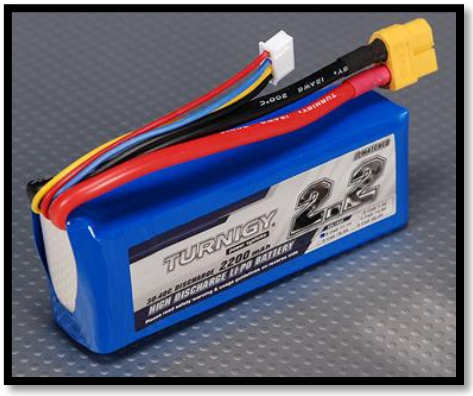


Figure 85: Turnigy LiPo Batteries

Lithium Polymer batteries (LiPo) will power the electronics for this payload. The reason LiPo batteries were chosen was due to their excellent track record in previous competitions. Only two LiPo batteries will be required for the payload: one for the motors, and one for the BeagleBone and its attached peripheries. Since each cell on a LiPo has a nominal voltage of 3.4V, a 3 cell LiPo will be used for the motors and a 2 cell LiPo for the BeagleBone. Each LiPo also has a mAh rating which measures the storage capacity for that battery. The mAh value tells you how much current the battery is able to deliver per hour. Each of the batteries will have a 2200mAh rating as this will allow the BeagleBone to run for around 4 hours, thus the payload has enough power to remain on the launch-pad for an hour. Further testing will qualify this theory. Turnigy LiPo batteries were chosen as they contain a fire-retardant material in case of fire. Table 36 shows the requirements the LiPo batteries satisfy, what features will help meet that requirement, and how they are expected to be verified.

Requirements	Features	Verification/Testing
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	The 2200mAh rating will allow the BeagleBone and all its peripheries to be active beyond the 1 hour. Fire-retardant material will be useful in case of fire.	The payload will be run with the batteries for at least an hour to make sure the mAh rating is appropriate. The motors will be tested to operate with the chosen LiPo.

Table 36: LiPo Battery Requirement, Feature, and Verification Table

Payload Power Distribution

In the system level view of the power distribution, our team's largest electrical concerns for the rover are battery life, communications, and allocating power to each component. We will be separating the power that runs to each motor, as well as the BeagleBone power by using separate batteries for the microcontroller and battery supply, respectively. Each battery will be regulated down from the battery voltage to each respective voltage that the components will need. The power for the microcontroller will be regulated by the

LM7805 IC. The power line for the motors will be regulated by the ESC's used in our current setup.

We will be utilizing the LM7805 voltage regulator (shown below) to give a regulated power supply to the BeagleBone. The 2200mAh 2-cell LiPo battery, that is being used to power the microcontroller, will provide up to 7.4 volts to the board. This voltage will then be stepped down by the LM7805, and exclusively power the BeagleBone. Per this regulator's datasheet, it will output a typical value of 5V (+/- 4%). This tolerance is well within what is needed for input to the BeagleBone micro. With the small delta for input/output voltages to the regulator, heat dissipation will not be a concern for powering the "brain" of the rocket/rover for the duration of the competition. The 7805 uses a maximum quiescent current of 8mA to regulate the voltage; a negligible load when compared to the <1A needed for the cape/micro combination.

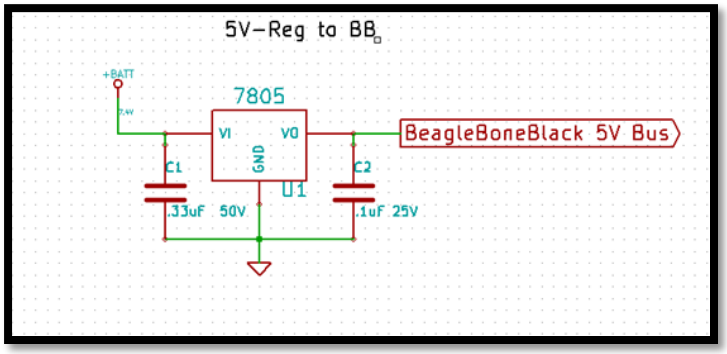


Figure 86: LM7805 Voltage Regulation Circuit

Per the BeagleBone website, it is recommended to run the BeagleBone at 5V (2A) supply when using any peripherals (1A otherwise). Depending on the processing speed, the microcontroller alone can draw up to 465mA. With our milliamp-hour rating, the setup will allow us to run at least the BeagleBone for 4 hours with margin enough for other peripherals. For standby power (and the 1 hour launch standby potential) we will be at an "idle" mode for the controller. The datasheet for the BeagleBone states that idle current draw will be around 170mA. At 1 hour, the standby for the board would potentially use less than 10% of our battery life; this allows us a safe margin to power the launch with, or without, a delay. Once the system design is matured, we will be able to perform system-level power testing.

MODE	USB	DC	DC+USB
Reset	180	60	190
UBoot	363	230	340
Kernel Booting (Peak)	502	350	470
Kernel Idling	305	170	290

Figure 87: BeagleBone Black Power Consumption

Our testing will first be concerned with the measurement of standby power with the added power draw of the custom PCB, GPRS cape, and camera. The camera is a Logitech C920 model. It is a commercially available component that will be powered via USB from

the payload. The C920 consumes 240mA at 5V. Although a datasheet was not readily available for the GPRS cape, our team researched the main communications chip on the sensor. Per the GE864 datasheet, the GPRS module uses only 62uA of power when in standby (desirable for idle launch delays). At full power, the maximum load of the cape can reach 420mA. Therefore, the max load for the BB and cape combined to under 1A. We expect to be able to keep the current power scheme assuming that our power supply stresses do not increase out of useful margin for launch performance. However, with the current design we can account for increased power needs through purchasing commercially available LiPo batteries with a larger mAh rating.

On further testing, we will need to test the motor systems to collect data for startup/peak and continuous-running power needs of the motors and ESC's. This has already begun at an isolated sub-system level. The sub-system will include the PWM circuit, battery, ESC, and motors. The isolated testing will validate our intended setup to show that we can power the selected motors at the chosen duty cycle for a liberal amount of time. Once, the sub-system is tested and qualified, we will begin testing at an integrated level on the assembled rover. For testing purposes, we have used equipment made available to us through LVL1 maker-space in Louisville, KY. Also available are the electronic labs at the University of Louisville. We are using load components to simulate power consumption. Oscilloscopes are being used to analyze and troubleshoot our PWM signal being sent from the PWM controller to the ESC.

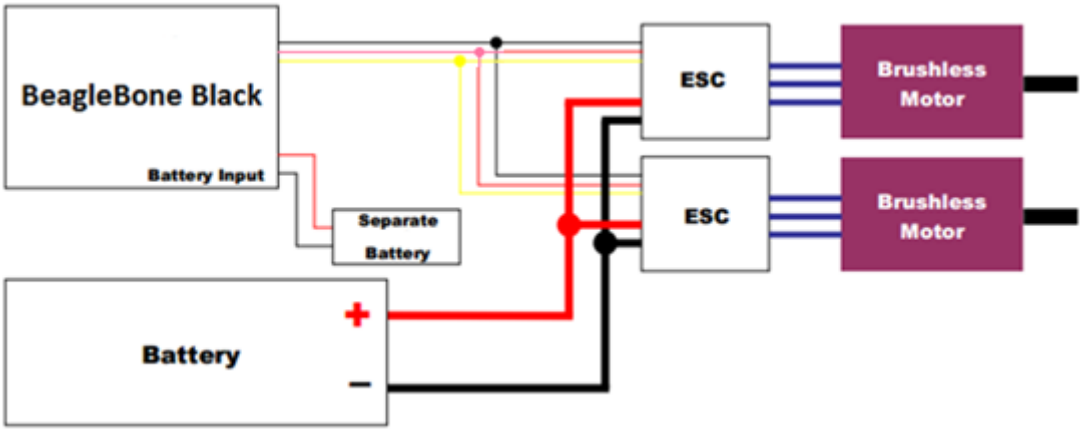


Figure 88: Payload Power Distribution

As shown in the illustration below, we will have a distributed power system for the rover. For power sourcing, we have isolated the receiver power bus from the motor power bus. Due to the noisy nature of motor to disrupt sensitive communications circuits, we wanted to keep the sources separate to ensure reliability of signal operations/transmissions. In our power design, we are using a modular ESC (electronic speed controller) to interface the 3 cell LiPo to the brushless motors. A desired feature of the ESC is the built-in overload protection that will add to our safety as well as reliability of the rover. With this overload protection, we can protect against damage to our motors, as well as unfortunate battery discharges that can cause fire and damage to the rover as well as its environment. Our team is making use of modular ESC for the precision of control we will gain with our

three-phase motor. While this is a substantial benefit, it does come with its own challenges. We have gained a lot of experience while designing and implementing the interface between the BeagleBone microcontroller (output) to the PWM data input of the ESC. The main research went into generation of a suitable PWM signal to be used to drive the ESC.

With our current setup, we are able to power both brushless motors with one 3-cell 2200maH battery. With use of the ESC, comes an ability to shut down the substantial power draw of the motors for launch standby. With the allowance of a motor standby we only have to power the ESC (not full motor potential) while awaiting launch. The ESC requires only 120mA at 5V for operation. This allows our team the option to run the ESC from the competition start, or we can "wake up" the device from liftoff. The standby option would allow us to bypass any unforeseen booting issues with powering the motor controller from a cold-boot at launch time.

Requirements	Features	Verification/Testing
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	The regulation circuit for the BeagleBone will insure that it doesn't overdraw too much power thus draining the battery. The motors will have their own battery.	Tests will be done that these circuits operate as intended.

Table 37: Power Distribution Requirement, Feature, and Verification Table

Custom PCB

Our team is designing a custom printed circuit board to contain the voltage regulator IC, a barometric pressure sensor, and a PWM controller for driving the ESC. We obtained the footprint of the BeagleBone's GPIO pins for the basis of the final PCB. To construct the schematic and layout, our electronics team is using KiCAD design software. This prototyping company has been recommended by previous colleagues at General Electric, as well as fellow students. Soldering of the PCB boards will be done by hand by the electronic team. This ensures quality on a one-by-one basis, rather than dependence on a mass-manufacturing procedure. We will use Advanced Circuits to fabricate the bare PCB boards for reliability and quick turnaround.

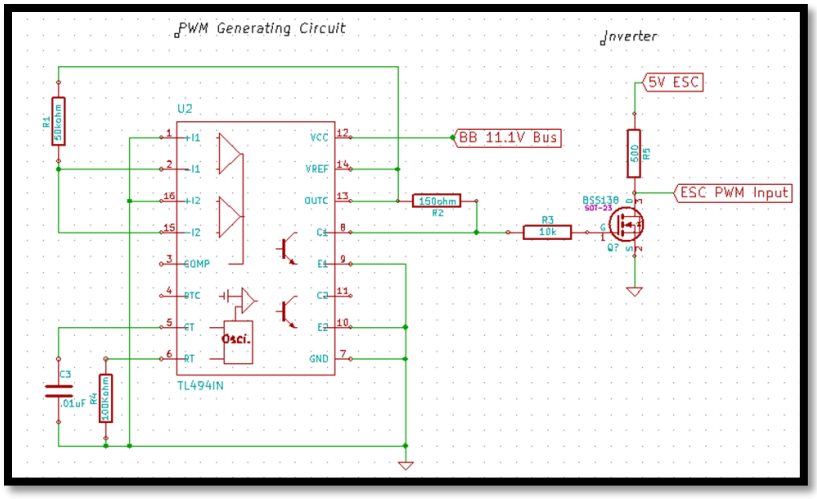


Figure 89: PWM Controller Circuit

Our team has already made discrete versions of the PWM and power regulating sub circuits for testing and qualification. Still needed is the construction of the pressure sensing circuit. We will follow an application circuit given on Sparkfun.com for our initial testing. The same design will be added to the board layout, barring any design flaws discovered through testing. By qualifying discrete circuits, we ensure functionality of our PCB when we have it manufactured, and we can fix any bugs found in the circuits. Any re-works after manufacturing will be implemented by hand on the manufactured board for time efficiency. Normally, availability of space on PCB's is of great concern. Fortunately, our circuits need relatively small amounts of real estate in comparison to PCB size. We will comfortably fit the regulating, pressure and the PWM circuit on the PCB. Layout design considerations include: heat dissipation for the regulator, placing charge capacitors close to regulator, placing timing capacitors close to PWM IC and pin assignments from the microcontroller's GPIO pins.

Regarding the custom PCB, the team decided to implement a hardware PWM setup instead of coding a software dependent PWM generator. We have more experience with hardware systems and have decided it is the most feasible route for our payload. The PWM control circuit that will take care of the interface is based on the TL494 PWM controller available from Texas instruments. Design considerations for this circuit include generating 1 kHz/5V square wave then inverting the signal through an N-channel MOSFET (BSS138) for it to finally be input into the ESC. Some calculations for this circuit include the resistance/capacitance combination ($frequency_{osc} = 1/(R*C)$) to allow 1 kHz operation and voltage to duty-cycle conversion. From the data sheet provided for the TL494 IC, we found that the DTC (dead time comparator) controlled our duty-cycle output. The correlation found was 100% duty-cycle at 3 volts, and 50% at 0 volts. We then needed to invert the signal through the MOSFET to use a duty-cycle less than 50% (needed for the ESC). The MOSFET also allows us to isolate the PWM circuit from the input of the ESC so that the ESC does not get overloaded. We were successful in controlling the motor with the design explained above.

Though our team has been planning the PWM circuit since the PDR was presented, a major change involves the IC chip used for PWM control. After having difficulty using the MC34023 IC, our electronics team could not locate supporting documentation for applications of the IC given on the data sheet. Fortunately, we located a different IC more suitable to our needs in terms of output voltage, and ease of hardware implementation; the TL494 included better documentation and was more easily constructed in lab. The inverter was also added to our PWM circuit for isolation concerns and voltage differences in the ESC input when compared to the TL494 output.

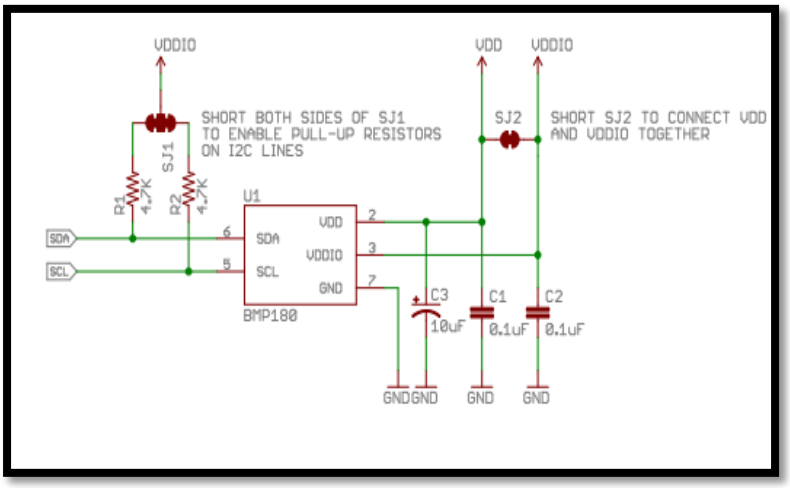


Figure 90: Barometric Pressure Sensor Circuit

For the custom made PCB board, we have designed for external connections. The 3 cell LiPo battery will be connected to the ESC's and TL494 PWM controller through 2 pin JST XA model connector. The connectors are rated for 250V/3A each. The 2 cell battery (7V) will be connected with the JST connector as well. It will be regulated through the LM7805 on the PCB then routed to another 2 positions JST XA header. From the XA header a joining XA housing will be received and connect directly to the microcontroller's barrel plug. Though it would be desired to receive the battery terminals directly to the PCB, our team could not locate a compatible header for the board-side connection. As for the remaining connections (servo, ESC data lines), we will be using open 3 position headers. We are designating orientation of the connections (i.e. "Data", "+", "-") through use of silk screen labels to be printed on the manufactured circuit boards. Pins used for custom PCB will be assigned from pins not in use by GPRS cape. This is determined from the GPRS cape datasheet.

Requirements	Features	Verification/Testing
The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The PCB will be custom made so the team can insure that all the payload circuits needed are on this board.	The PCB is not tied to any circuitry for the recovery of the rocket.

*The rover must successfully separate itself from the parachute once landed.	The accelerometer to detect landing and servo connections for the Parachute Cam will be on this PCB.	Tests will be done to insure the components on the PCB work correctly.
*The rover must travel at least 20 feet once it has landed.	The PWM circuit for the ESCs will be on the PCB.	Tests will be done to insure the circuit works correctly.

Table 38: Custom PCB Requirement, Feature, and Verification Table

Overall Flight Algorithm

The hazard payload will all be controlled by the BeagleBone Black microprocessor which was chosen due to its capabilities for handling the software's expected demands. To control the payload's "brain", the software package the team is developing will be responsible for controlling everything aboard the hazard detection payload from the time it's activated until it is retrieved. The part of the program that will use most of the BeagleBone's resources is the image processing algorithms. To reduce the strain on the BeagleBone, the software will be optimized as much as possible. An overview of how the different parts of the payload software package will operate is described below.

Changes Since PDR

A few changes have been made to the overall flight algorithm since PDR. These are mostly minor logical tweaks to fix errors. Issues addressed:

- In the PDR, the device failure reporting step resulted in stopping the entire launch process, even if a non-critical error occurred. This has been modified to make the launch process continue if hardware setup errors occur, and give the team the option of continuing to launch, depending on the device(s) that failed.

- In the PDR, GPS coordinates were sent continuously from the payload to the ground station prior to launch detection. This step has been removed, because: 1) the GPS coordinates of the launch pad can be closely approximated by the coordinates of the first packet sent to the ground station. 2) Continuously sending text messages to the ground station will cause unneeded battery drainage, which can be an issue if launch time is significantly delayed.

- In the PDR, the team used an accelerometer to detect launch and landing events. The plan was to detect a sudden, large force being applied to the rocket, and assume that force was coming from the rocket motors. This decision has been changed to use a pressure sensor instead. The pressure sensor will be used to detect change in altitude, which provides a stronger guarantee that the detected event is the rocket launch, rather than a sudden jarring of the rocket.

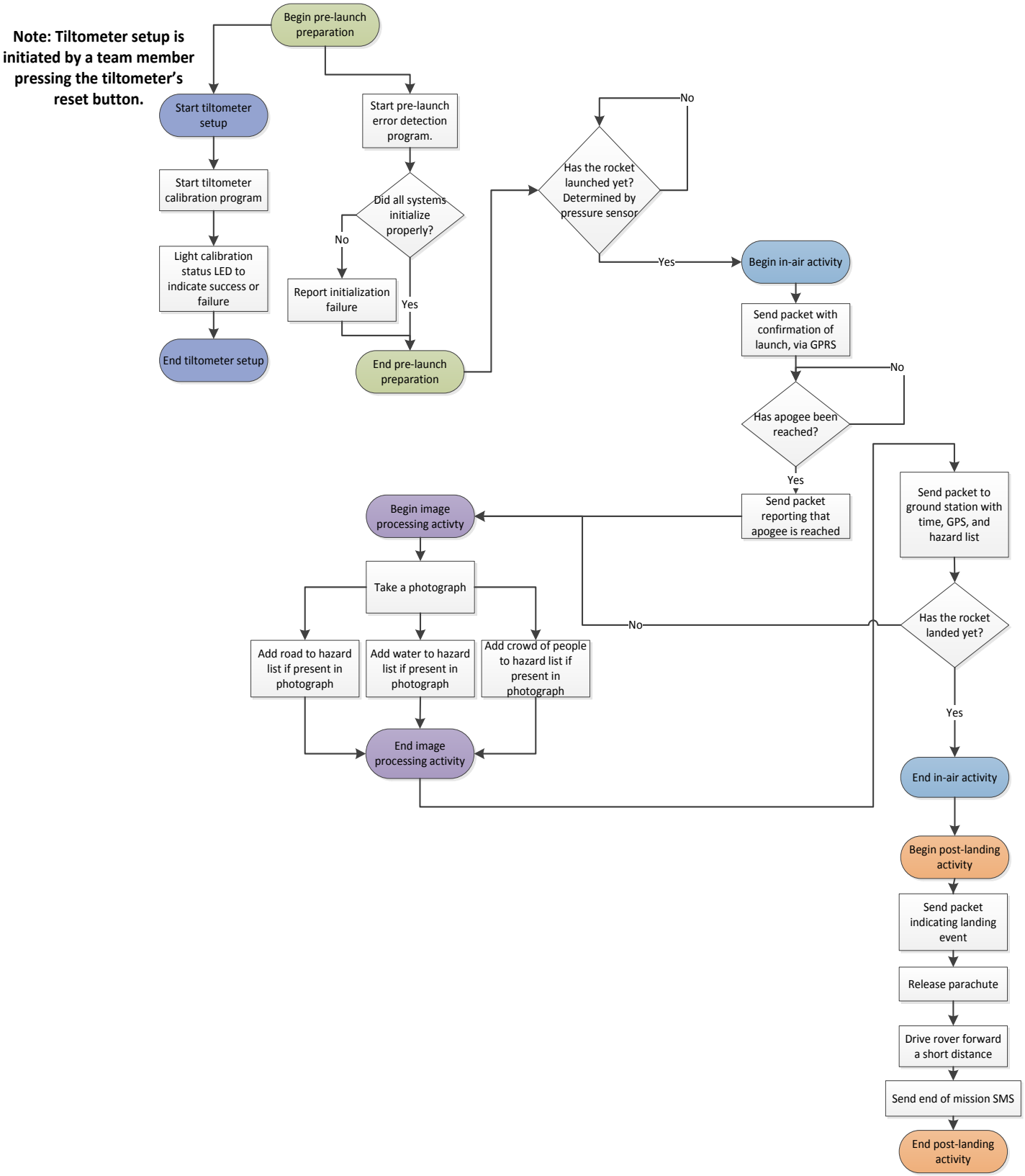

Note: Tiltometer setup is initiated by a team member pressing the tiltometer's reset button.
Begin pre-launch preparation
Start tiltometer setup
Start tiltometer calibration program
Light calibration status LED to indicate success or failure
End tiltometer setup
Start pre-launch error detection program.
Did all systems initialize properly?
No
Report initialization failure
Yes
End pre-launch preparation
Has the rocket launched yet? Determined by pressure sensor
No
Yes
Begin in-air activity
Send packet with confirmation of launch, via GPRS
Has apogee been reached?
No
Yes
Send packet reporting that apogee is reached
Begin image processing activty
Take a photograph
Add road to hazard list if present in photograph
Add water to hazard list if present in photograph
Add crowd of people to hazard list if present in photograph
End image processing activity
Send packet to ground station with time, GPS, and hazard list
Has the rocket landed yet?
No
Yes
End in-air activity
Begin post-landing activity
Send packet indicating landing event
Release parachute
Drive rover forward a short distance
Send end of mission SMS
End post-landing activity

Figure 91: Overall flight algorithm flowchart

Tiltometer setup

The first step in the flight algorithm is to initialize the tiltometer. The setup program will set the proper accelerometer and gyroscope offsets on the tiltometer so that the device considers its orientation on the launch pad as its frame of reference. If tiltometer calibration fails, an LED will be lit indicating that the failure occurred, to alert the team. The tiltometer is not part of the hazard detection payload but is included in the flowchart as it is part of the flight activities for the rocket.

Pre-launch preparation

During pre-launch preparation, every device in the payload will be powered on and checked for successful startup. If any device fails to start, it will be added to a list of devices that failed to start. The failed devices list is then used to light a set of LEDs indicating which devices failed to start, or that no devices failed to start, which allows the team to decide to proceed or not.

Then, the program will continuously poll the pressure sensor to determine if the launch event has occurred. When launch is detected, the rocket will proceed to the in-air activities phase of operation.

In-air activities

As soon as the in-air activities phase begins, the payload will send an SMS to the ground station indicating that the launch event occurred. Then, the program will continuously wait to detect apogee from the pressure sensor. Once apogee is detected, another SMS message will be sent to the ground station indicating this event.

Image processing activities

After apogee is detected, the payload enters its image processing phase. In the image processing phase, an image is taken from the onboard camera. Then, the image is scanned for evidence of water, roads, and crowds of people, and the presence or absence of these hazards is recorded. After the image is scanned for hazards, an SMS is sent to the ground station with hazard detection results. Finally, the program will check for landing through the pressure sensor, and if landing is detected, the post-landing activity phase will begin. If landing is not detected, the program will continue extra image processing steps.

Post-landing activities

After the rover lands, it will first send an SMS to the ground station indicating that landing has occurred. Then, the rover will wait 10 seconds to stabilize before releasing the attached parachute. Once the parachute is released, the rover will drive forward a few feet, and send a final SMS, thus completing the mission.

Software Boot Sequence

The purpose of the boot sequence it to reliably initialize all relevant software and hardware components of the rocket payload, and report any startup errors for debugging purposes. Figure 92 shows a flowchart of our current boot sequence.

Changes since PDR

The only change relevant to the software boot sequence since PDR is the substitution of the launch detection accelerometer with a pressure sensor. This decision was made to increase confidence that the launch detection event is detected due to a rapid change in altitude, rather than from experiencing a large, sudden force, which could occur from dropping the rocket, for example.

Initialization

The main driver of the boot sequence is an initialization script that is run every time the operating system is rebooted. The system's software environment (Linux on a BeagleBone) reboots every time power is supplied to the board. When the team assembles the rocket, the board will be provided power, which will start the operating system, and thus begin the boot script.

The boot script initializes all hardware, including the GPRS unit, accelerometers, motors, etc. Every hardware unit that fails to initialize properly is added to a list of incorrectly initialized devices.

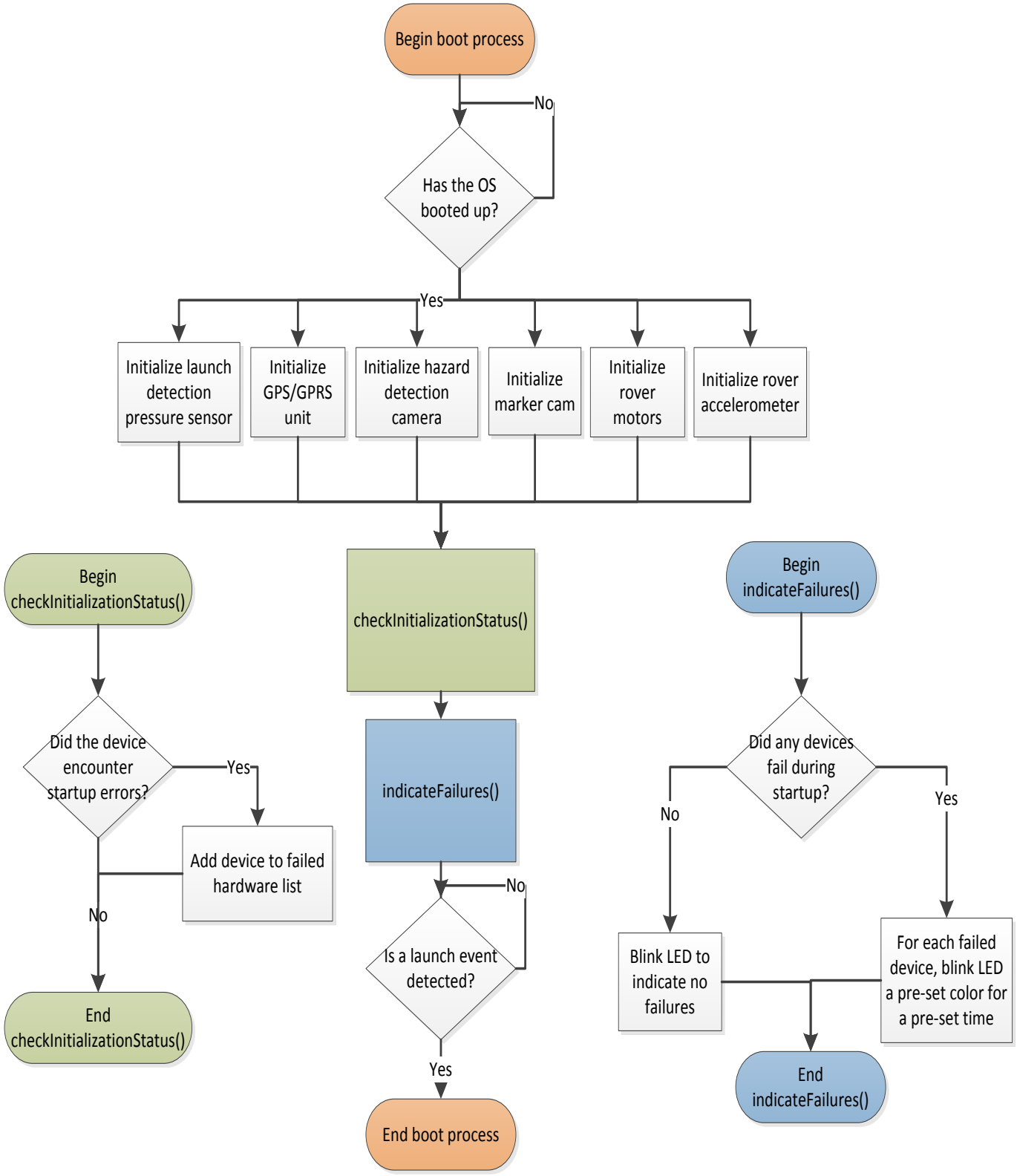


Figure 92: Boot Process Flowchart

Status indication

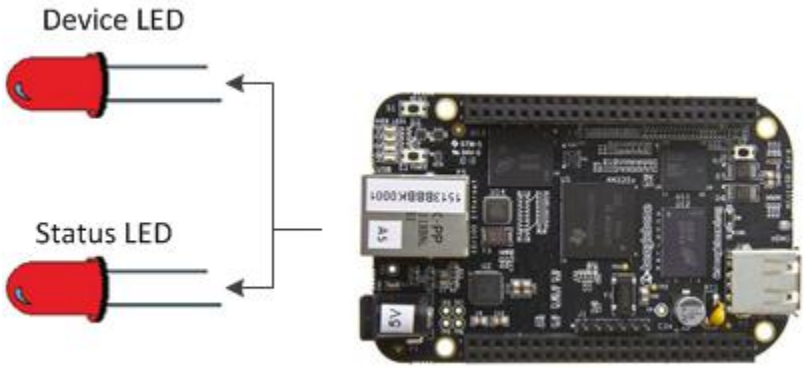


Figure 93: Boot Status Indication Setup

During the boot process, a pair of RGB LEDs is used to indicate the status of the boot process. The first LED (the “Status LED”) is used to indicate the current stage of the boot process, and displays values that indicate: devices are currently booting up, boot up is complete with non-critical errors, boot up is complete with critical errors, or boot up completed with no errors. The second LED (the “Device LED”) is used to indicate any specific errors that occurred during boot up. Each hardware device is assigned an RGB color, and after boot up completes, the system will repeatedly cycle through every device in the failed devices list, and light Device LED for a short time period. This system will allow the team to immediately determine any hardware failures immediately before launch time. This gives the team the information needed to make an informed decision on whether to launch or not.

Launch detection

After the above boot sequence has completed, the boot script will enter a loop where it continuously polls the pressure sensor to check for a launch event. If the detected pressure difference is large enough that the system can guarantee it is coming from the rocket engines, the script breaks out of this loop and enters the in-flight phase of activities.

Data Communications

The purpose of this part of the software package is to design a reliable and efficient method to communicate: detection of environmental hazards, sensory data, and detection of discrete phases of the launch cycle to a ground station.

Changes since PDR

The primary change made since PDR is the addition of an extra node in the communications system. At the time of PDR, there were two nodes in the system: The BeagleBone Black, and the team’s web server. For the final team design, the team has

added one extra node – a ground station – to the design. The reason for adding this extra node to the system was to increase ease of development. In the previously used system, a direct network connection was required between the web server and the BeagleBone Black. Doing this requires establishing an Internet connection over a cellular network. This approach proved more difficult than anticipated, and the team has decided to first transmit data to a ground station, where it is then forwarded to the web server.

The primary reason for making this adjustment is that the team is confident that there will not be any issues uploading data to the web server from an Android-based ground station. During development, there were issues attaining a reliable Internet connection on the BeagleBone Black, so it was deemed safer to add extra complexity for a stronger guarantee that file uploading will work.

Data Transmission

Data will flow in the following manner in the system:

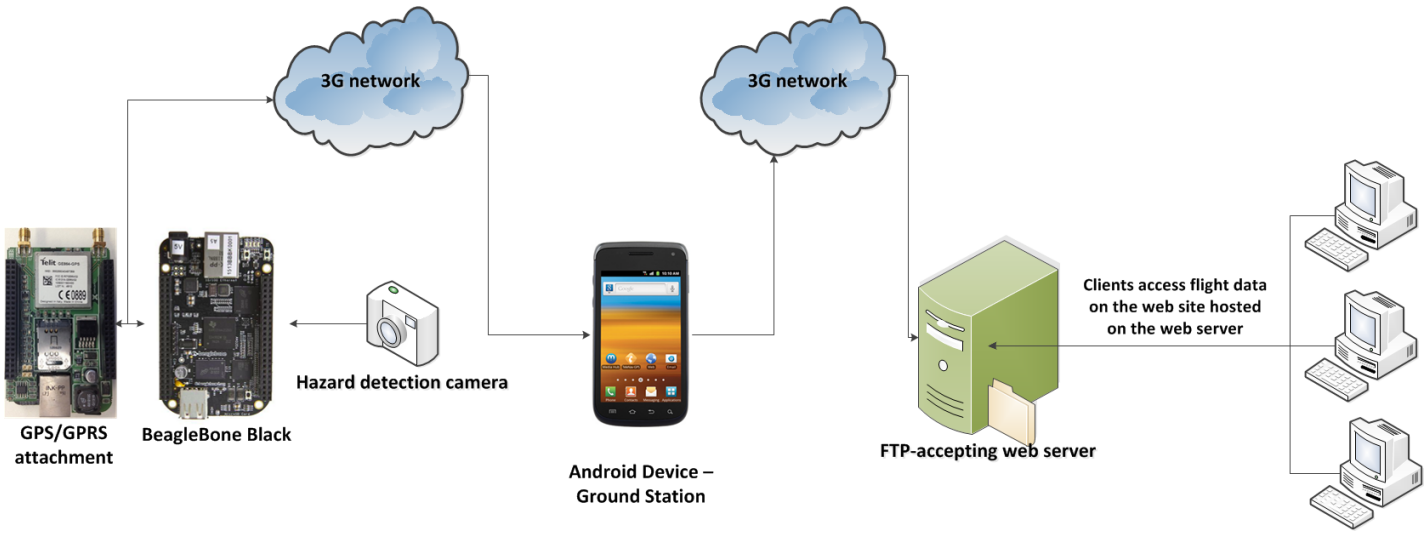

3G network
3G network
GPS/GPRS attachment
BeagleBone Black
Hazard detection camera
Android Device – Ground Station
FTP-accepting web server
Clients access flight data on the web site hosted on the web server

Figure 94: Data Flow Layout

The BeagleBone Black is the central component of the payload, integrating data from the hazard detection camera and using the GPRS attachment to transmit data processing results to the ground station. The GPS/GPRS attachment provides GPS coordinates and the velocity of the payload with respect to the Earth's surface. The BeagleBone Black processes the camera's and GPS unit's data and generates a text message to be sent to the ground station. The text message contains timestamp-associated GPS coordinates, and a list of every hazard detected in the most recent image that was processed. The SMS message structure is as follows:

Field	Length [in characters]	Description
'^'	1	Begin transmission control character – used to signal beginning of the current transmission.
Message header		
Message body		
'$'	1	End transmission control character – used to signal end of the message.
Total length [in characters]:		max=39, min=37

Table 39: SMS Message Structure

Field	Length [in characters]	Description	Example
Packet type	1	Character that specifies if this is a routine hazard-detection message, or a special event [IE: launch, apogee, landing] notification message.	'H' = hazard detection message 'E' = event notification message
Start time	10	The time when GPS coordinates were retrieved. Roughly equivalent to the time when the scanned image was taken. Recorded in UTC.	'090446.000' which converts to '09:04:46.000 UTC'
GPS Status	1	Indicates if the GPS unit had a reliable connection when coordinates were read in for this message.	'A' = data is ok 'V' = data is invalid
Latitude	<= 10	Specifies the latitude of the payload at the time of reading. Encoded in Decimal Degrees and Minutes.	3816.1785 which converts to +38° 9' 42.426"
Latitude modifier	1	Modifies the latitude to indicate if it points North or South.	'N' = North 'S' = South
Longitude	<= 10	Specifies the longitude of the payload at the time of reading. Encoded in Decimal Degrees and Minutes.	08541.9846 which converts to +85° 25' 11.4456"
Longitude modifier	1	Modifies the longitude to indicate if it points East or West	'E' = East 'W' = West
Max. total length [in characters]:		34	

Table 40: SMS Header Structure

Field	Length [in characters]	Description	Example
Evidence of crowd of people?	1	Indicates whether or not a crowd of people was detected in the most recently scanned image.	'1' = crowd detected '0' = crowd not detected
Evidence of a road?	1	Indicates whether or not a road was detected in the most recently scanned image.	'1' = road detected '0' = road not detected
Evidence of a body of water?	1	Indicates whether or not a body of water was detected in the most recently scanned image.	'1' = body of water detected '0' = body of water not detected
Total length [in characters]:		3	

Table 41: SMS Body Structure – Hazard Detection Message

Field	Length [in characters]	Description	Example
Event type	1	The type of event that was detected. Can be a launch event, apogee event, landing event, or mission ending event.	'L' = Launch 'A' = Apogee 'N' = Landing 'E' = Mission end
Total length [in characters]:		1	

Table 42: SMS Body Structure – Event Notification Message

Message content	Description
^H083512000A3816.1785N08541.9846W101$	A hazard detection packet was sent at 8:35:12 UTC, at coordinates (+38° 9' 42.426", +85° 25' 11.4456"), which detected a crowd of people and a body of water.
^E083512000A3816.1785N08541.9846WE$	An event notification packet was sent at 8:35:12 UTC, at coordinates (+38° 9' 42.426", +85° 25' 11.4456"), indicating that the mission has ended.

Table 43: Message Examples

SMS messages start with a header section contains metadata about the packet. The header contains the type of packet that is being sent and the GPS coordinates at the time of transmission. There are two types of packets that the payload will send, which are noted in the packet type field. 'Hazard detection' messages are meant to indicate that an

image was scanned for hazards, and the presence or absence of all hazards that were scanned for. 'Event notification' messages notify the ground station that a special event has just occurred in the launch sequence. For our purposes, event notifications will be limited to notification of rocket launch, apogee, and landing. A body section immediately follows the header section, with the results of either hazard detection or event notification.

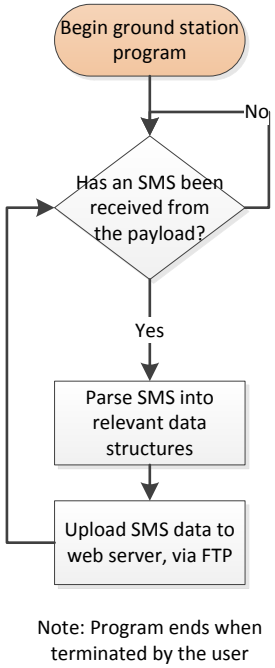

Begin ground station program
No
Has an SMS been received from the payload?
Yes
Parse SMS into relevant data structures
Upload SMS data to web server, via FTP
Note: Program ends when terminated by the user

Figure 95: Ground station flowchart

SMS messages are transmitted from the payload to the ground station – a cellular phone from one of the team members. The ground station's program logic is simple. The ground station contains a program that will continuously listen for incoming SMS messages from the payload. When a message arrives, the message will be parsed, and transformed into a formatted text file to be uploaded to the web server.

From there, the team's web server will notice that a new text file has been uploaded. The server will update information on the web site to indicate to visitors the event(s) seen, and the payload's current hazard detection status.

Test results

Data communications between the GPRS unit and the ground station have been tested and repeatedly proven to work. The team has a functioning program that allows users to enter an arbitrary phone number to message. A message will then be sent to that number with the current GPS coordinates read from the GPS unit. The program is reliable enough that the team was able to use it at an educational engagement event to send participants messages from the rocket's electronics.

Data from the GPS unit has been verified to work in one location, based on viewing the read-in GPS coordinates in Google Maps. The team plans to further verify the accuracy of the GPS device by testing in multiple locations to verify that the data is accurate in multiple locations, and to read in GPS data repeatedly over a span of time (1-2 weeks) in the same location, to verify that the unit consistently gives accurate results.

It has been demonstrated that the team's web server is able to retrieve FTP uploads. The team successfully transferred FTP files from their local computers to the web server, and viewed their contents on the web server.

Launch Event Detection

The goal of this part of the software package is to implement a system to reliably detect the rocket's launch, apogee, and landing events, in order to trigger other events in the rocket control algorithm.

Drawings and specifications

There are three separate algorithms used to detect different events in the rocket's lifecycle: launch, apogee, and landing detection.

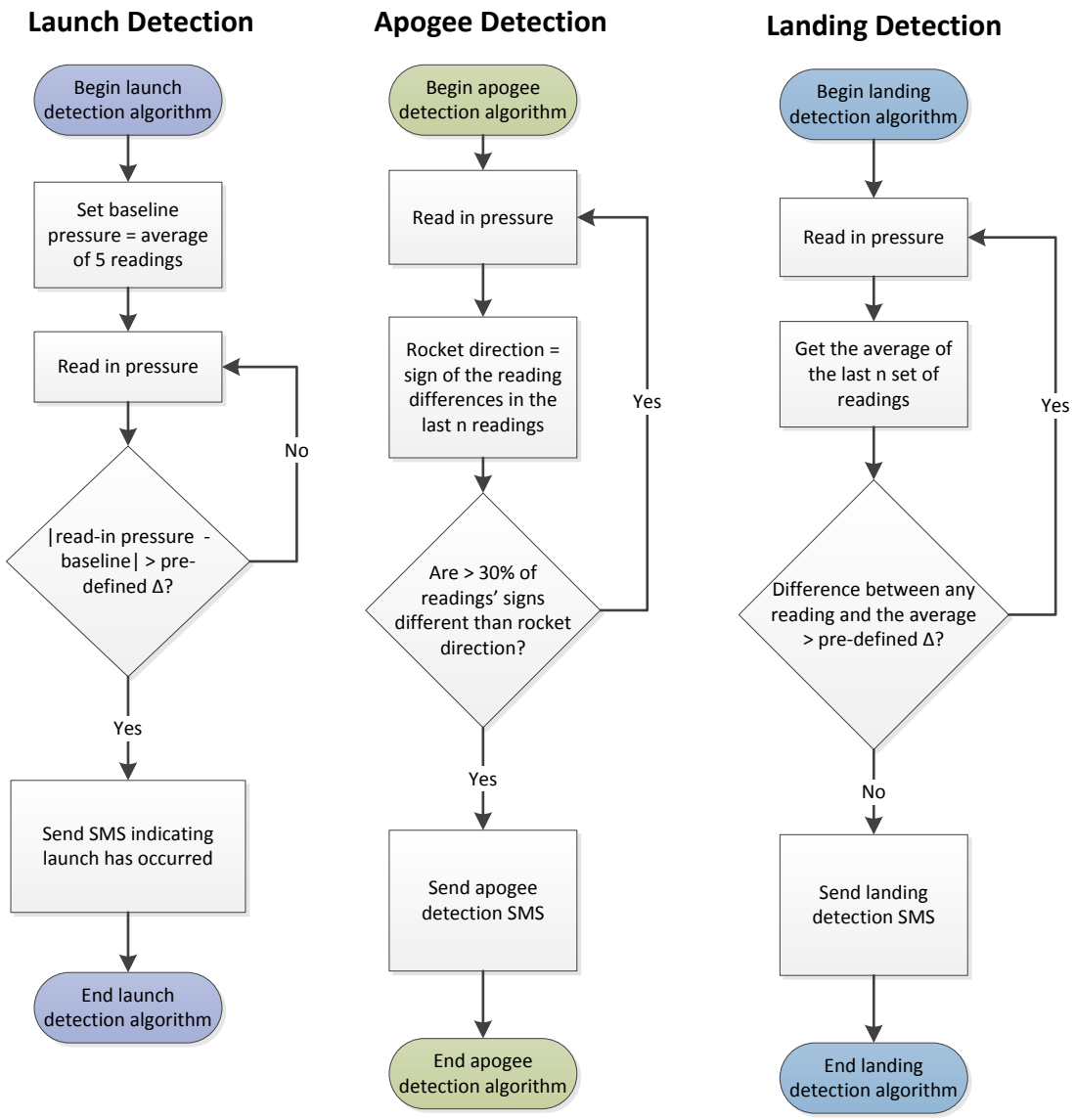

Launch Detection
Begin launch detection algorithm
Set baseline pressure = average of 5 readings
Read in pressure
|read-in pressure - baseline| > pre-defined Δ?
No
Yes
Send SMS indicating launch has occurred
End launch detection algorithm
Apogee Detection
Begin apogee detection algorithm
Read in pressure
Rocket direction = sign of the reading differences in the last n readings
Are > 30% of readings' signs different than rocket direction?
Yes
Yes
Send apogee detection SMS
End apogee detection algorithm
Landing Detection
Begin landing detection algorithm
Read in pressure
Get the average of the last n set of readings
Difference between any reading and the average > pre-defined Δ?
Yes
No
Send landing detection SMS
End landing detection algorithm

Figure 96: Pressure sensor event detection

The launch detection algorithm will first detect a baseline pressure. This is the air pressure experienced while the rocket sits on the launch pad. An average of five readings from the pressure sensor will be used to set the baseline amount. Then, the program will enter a loop where it continually reads from the pressure sensor. After each reading is taken, the program will check if the difference between the reading and the baseline is larger than a pre-defined amount. When a large change in pressure is detected (larger than the pre-defined amount), the launch event will be considered detected, the program will exit its loop, and an SMS will be sent indicating that launch has occurred.

To detect apogee, the rocket will keep a running record of its most recent n pressure sensor readings. The value of n will be determined by the team during testing. The program will determine the sign of the difference between successive pressure readings,

and wait until it detects a series of n readings where a certain percentage of the signs differ. When apogee occurs, the rocket's direction will be changing from up to down, so detecting a difference in pressure sensor signs will indicate apogee. Once apogee is detected, an SMS will be sent indicating that apogee occurred.

The landing detection algorithm will also keep a record of the previous n readings. Again, the value of n will be determined during testing. First, the average of these n readings is calculated. Then, the difference between each of the n readings and the average will be calculated. If any of these differences are larger than a pre-determined threshold, it is determined that landing did not occur. When all n readings from the pressure sensor are less than the threshold, landing is detected, because the values from the pressure sensor are suitably stable. Once landing is detected, another SMS will be sent indicating the landing event.

OpenCV

The software package that is going to be used is an open source library for image processing called OpenCV, short for "Open Source Computer Vision Library." As the name implies, OpenCV is free to use under the open source BSD license. OpenCV is designed for computational efficiency with a strong focus on real-time image processing applications. Due to its wide popularity, OpenCV supports languages varying from C, is a cross-platform library which has Linux support. Not only does OpenCV support the same operating system (OS) as the BeagleBone (Linux), but it has full support for numerous programs written in C++, Python, and Java. OpenCV is currently used in various applications such as robotics, motion tracking, and object identification thus making the perfect tool for our requirements. Our choice of language will vary from Python to C++ and will be combined for the most optimal solution on the BeagleBone. This will help us effectively track hazards.

The task of obstacle detection will not be a trivial one as not all hazards can be detected with simple algorithms. The OpenCV library requires certain color ranges which would define the hazards in this case. This process of converting images from BGR (Blue, Green, Red) to HSV (Hue, Saturation, Value) allows color differentiation. Implementation will be applied on the most common hazards that we expect to encounter when we are in flight. Some of these hazards include water, roads, and crowds of people. The current plan is to detect these hazards, and then add more hazard types later, depending on development progress.

Color variation and edge detection methods

Another approach that will be taken includes detecting edges and color variation to detect objects. This works by providing an input image from a live camera feed and processing it through numerous image manipulations using OpenCV. One such input would be smoothing the original images using the Gaussian kernel thus making the output with a lot more depth. Then change the image from BGR to HSV using a defined color range thus filtering that out.

Figure 97: Salt Flats unfiltered - launching area

Figure 98: Salt Flats filtered - launching area where the cars and mountains are added to the hazard list and filtered.

Hazard data transmission

After detecting the different hazards, our program will store a list of these for a real-time data feed which is transmitted to the ground station, and then later a web server. The web server will have the FTP protocol enabled, which the program on board the BeagleBone will use to send and receive data to and from the devices. The medium between the two will be a phone (the ground station) which will receive a text message from the BeagleBone, which will then be forwarded over to the web server using an app which will watch for a specific phone number for the message. This app will then transfer it over to the web server through FTP as mentioned before. The real time hazard data will be first

compressed on the BeagleBone into a 0/1 format. This format will then be interpreted and sent over to the web server, which will cause the hazards list to be shown in real-time on the server.

OpenCV Hazard Detection Process

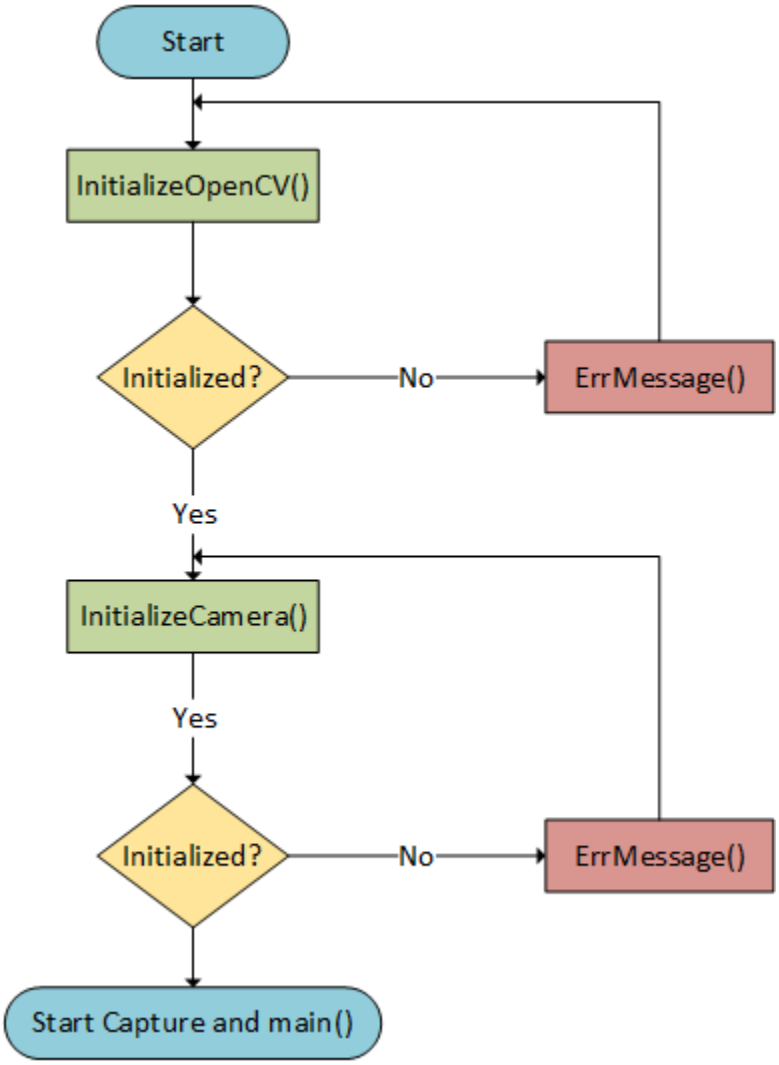


Figure 99: First steps of the object detection. Initialize all necessary functions while dealing with any errors. Start capture from the main method.

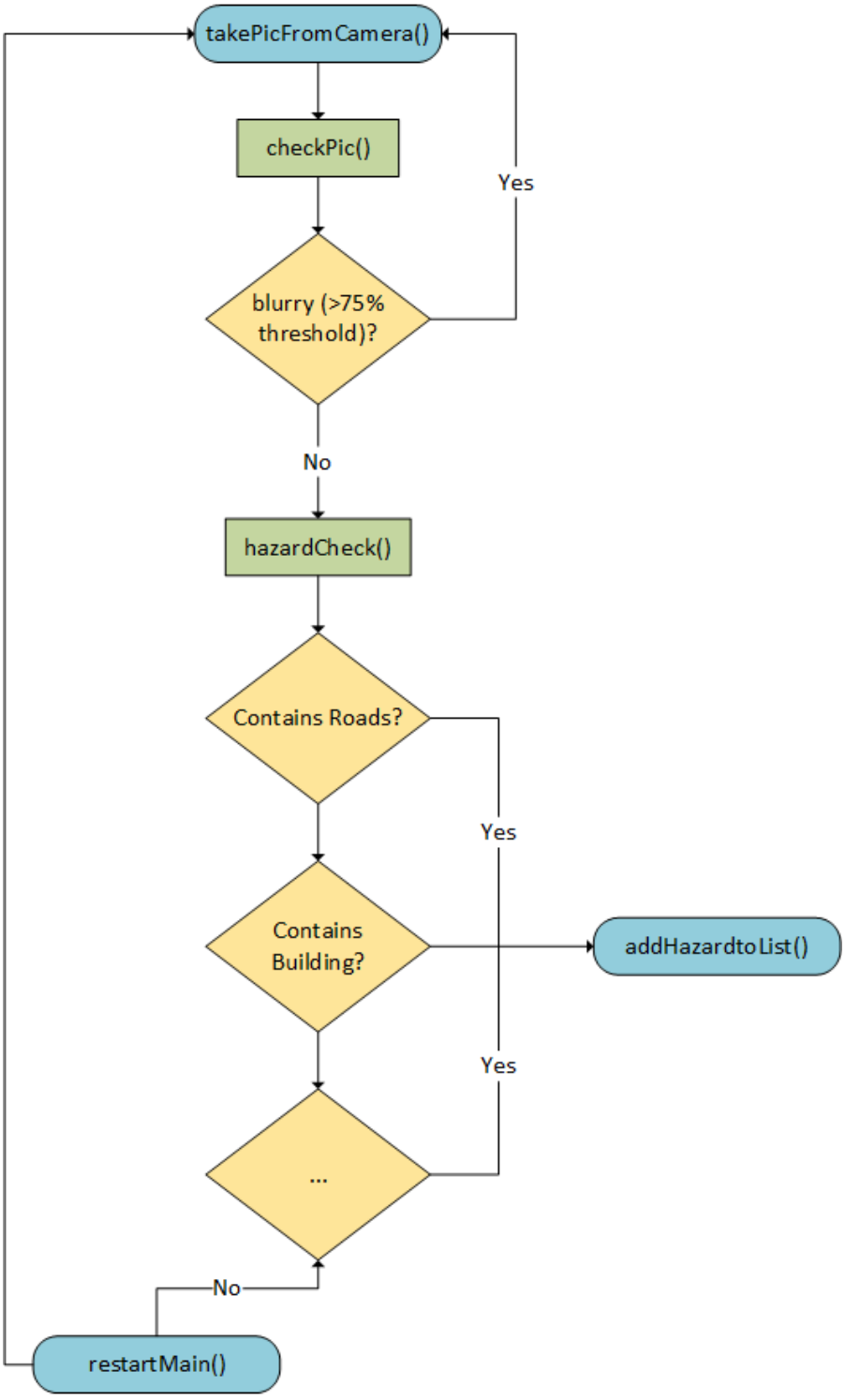


Figure 100: Second steps of the object detection. Start taking input images from the camera feed and start checking for accurate and non-blurry images. Add detected hazards to a Hazard List. If no hazards found, restart main method.

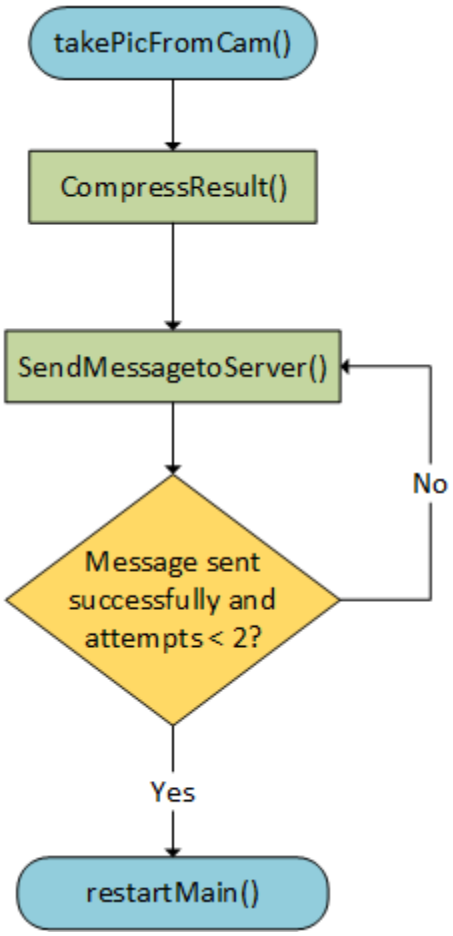


Figure 101: Third step of object detection. Capture image from camera and created hazard list and compress the result for remote send. Send message to server and confirm the send. Restart main method again and continue with repeat.

The basic process for the program is outlined above. As pictured, the program will start by initializing of both OpenCV and the Camera which are integral parts of this process. All the error and initialization checking will be done before the program goes forward. After it is verified, the main() program loop will start and the first method, takePicFromCam() will be run. After this method run, another verification method called checkPic() will be initialized which will check for any blurriness which will have a set threshold of greater than 75%. Once this is completed, the main hazardCheck() algorithm loop will begin which will start populating the list of hazards. Once this is completed, if at least one hazard has been detected, the process will continue onto sending the compressed message to the ground station server. Once a successful link is established, real-time data will be available on the team's web page. If no hazards are found and/or sending to server completed, the program starts back at the main() method and starts the process again.

Requirement	Features	Verification/Testing
The payload shall incorporate a camera system that scans the surface during descent in order to detect potential landing hazards.	OpenCV has functions that allow it to have control over the camera so that it can take pictures as necessary.	Tests have been conducted to make sure we can control the camera through OpenCV.
The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.	OpenCV is an image processing library that can is compatible with the BeagleBone. OpenCV can be coded to detect certain objects.	Further tests will be conducted to verify that OpenCV can detect hazards via BeagleBone.

Rover Design

A rover was chosen to integrate the electronics onto the rocket. The reason for choosing a rover layout is that it adds significance to the hazard detection part of the payload since this system could be used to detect landing zones for future rovers going to other planets. Figure 102 shows the layout of the rover with all the hardware modeled to scale. The rover design is based off the ZIL-2906 vehicle designed by the Soviet Union to retrieve cosmonauts in difficult terrain, as well as the Hot Wheels Terrain Twister which is an RC toy.

The rover is 5.11” wide, 4.64” tall, and 17.45” long and is expected to weigh around 5 lbs, but this might vary slightly as the weight of the 3D printed components are still unknown. The rover is sized to fit inside of the 6in diameter airframe for the fairing. The parts requiring 3D printing have already been sent to the rapid prototyping lab at the university and the team is awaiting their delivery.

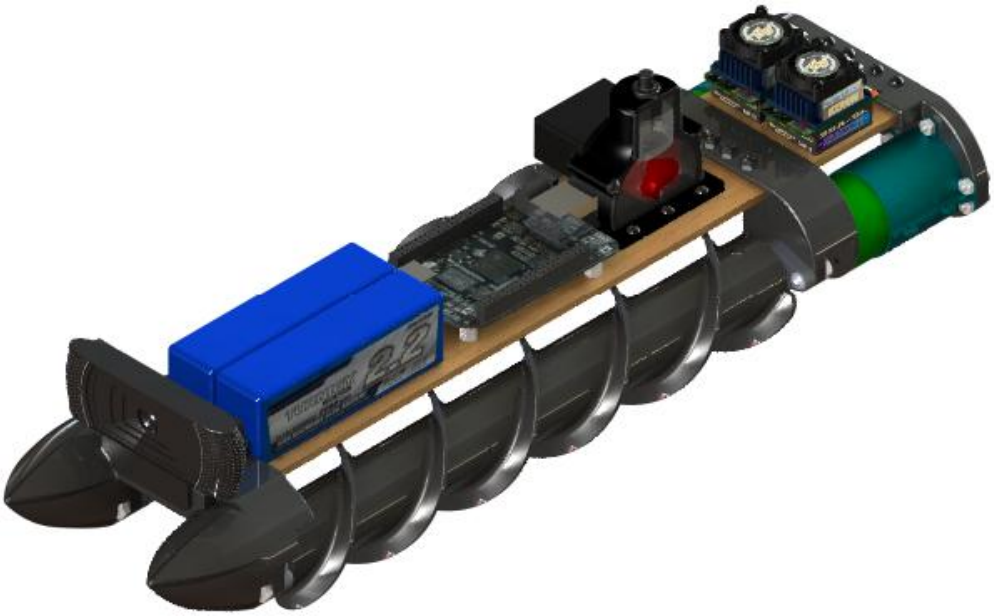


Figure 102: Rover Model

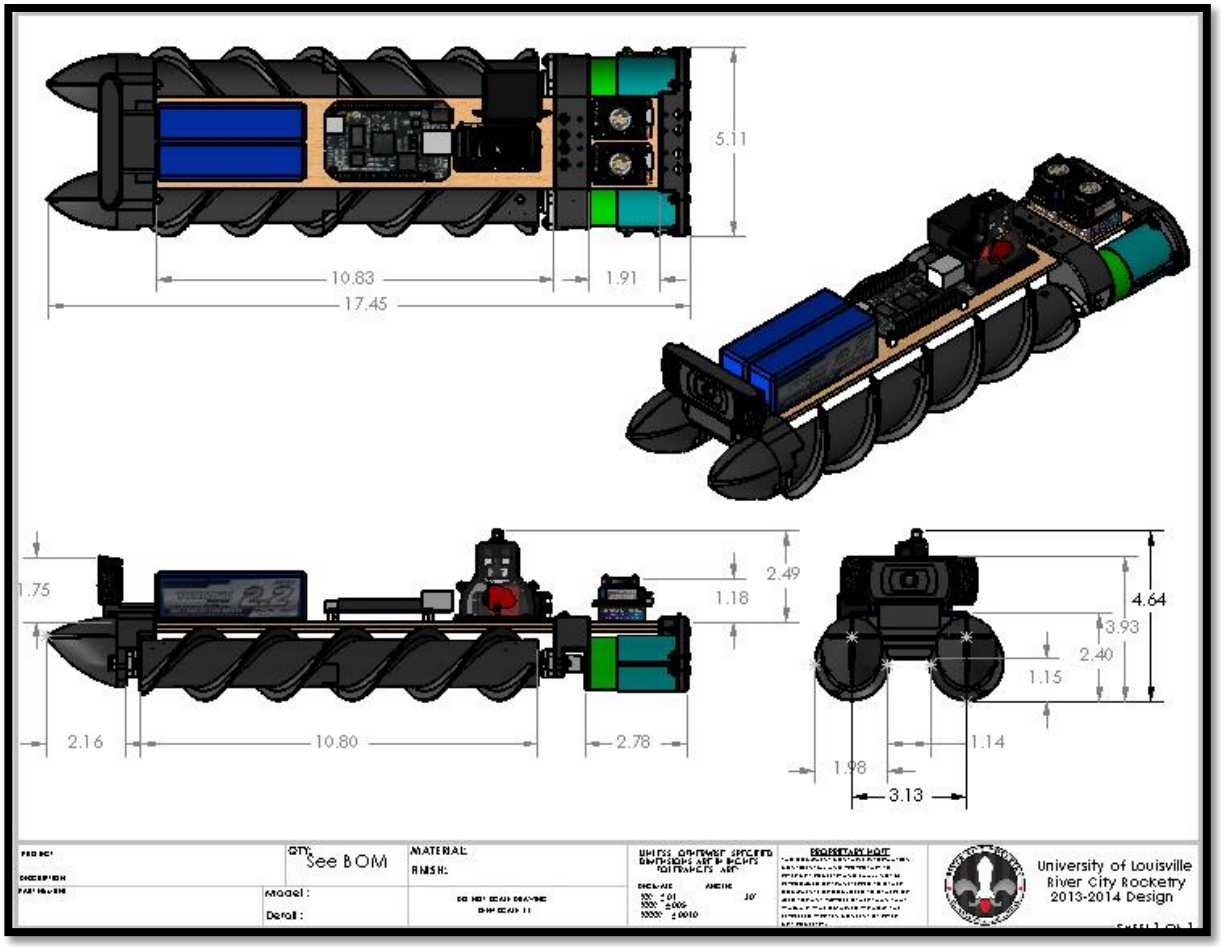


Figure 103. Rover General Dimensions

Electronics Integration

All of the electrical components will be placed on top of a 15.5" x 2.5" wood platform that is ¼" thick. Testing will be conducted once the 3D printed parts arrive to determine if the platform should be converted to aluminum to better handle the stresses upon deployment or landing. The camera will be mounted in the front of the rover so that it will be facing downwards during descent. The foldable stand that comes with the camera will be cut in half and the remaining part will be attached via screws onto the platform. The LiPo batteries will have a sheet metal cover that will hold them in place. This cover will have tabs to allow it to screw onto the platform. The ESCs will also have a similar sheet metal cover. These covers are not shown on the rover as they were not modeled. To further insure that the LiPos and ESCs do move, small strips of Velcro will be placed in between them and the platform.

The BeagleBone will be attached to the electronics platform via Nylon male-female standoffs. The standoffs will screw into the platform and then Nylon screws will hold down the BeagleBone thanks to the through-holes it has. The reason Nylon was chosen was

that it is non-conductive to electricity. To attach the Parachute Cam, screws will be used to attach it and the servo onto the platform. These screws will go through tabs built into the Parachute Cam. To attach the motors, clamps will be used that go around the motors and hold them in place. These clamps will then screw into the end plate of the rover.

Figure 104: Motor Clamp

Most of the wires for the electrical components will be routed underneath the electronics platform. The wires will be held in place with zip-ties. Some of the wires on the components will have to be cut due to their length, such as the USB cable from the webcam which is 6 feet long. Special attention will be used when doing this as it could impact the payload's performance. After the wires are soldered together, tests will be conducted to insure that the components still function as intended. The electronics platform will have holes in it to allow the wires to go to their respective components.

Power Screw Design

The main feature of this rover is the power screws which will be used for movement. Each of the power screws will be 3D printed out of ABS plastic since their complex shape would be difficult to machine ourselves and expensive to contract out. They are currently being printed by the rapid prototyping lab at the university. The screw slope angle was chosen as 16 degrees due to information from a previous study ("Terramechanics-based Propulsive Characteristics of Mobile Robot Driven by Archimedean Screw Mechanism on Soft Soil" 4946-4951). Also based on this study, the pitch for the threads was chosen to be 4 inches, and the blade height is 3/8 inches.

Due to the size limitations of the 3D printers, each screw will be made out of two parts. To hold the power screws together, plastic cement will be used on the tabs that join the two halves. Screws will be added if more support is needed, and if that doesn't hold, a redesign will be made. The total length of each screw is 10.8 inches. Figure 105 shows an exploded view of the power screw assembly to better illustrate how it will be built.

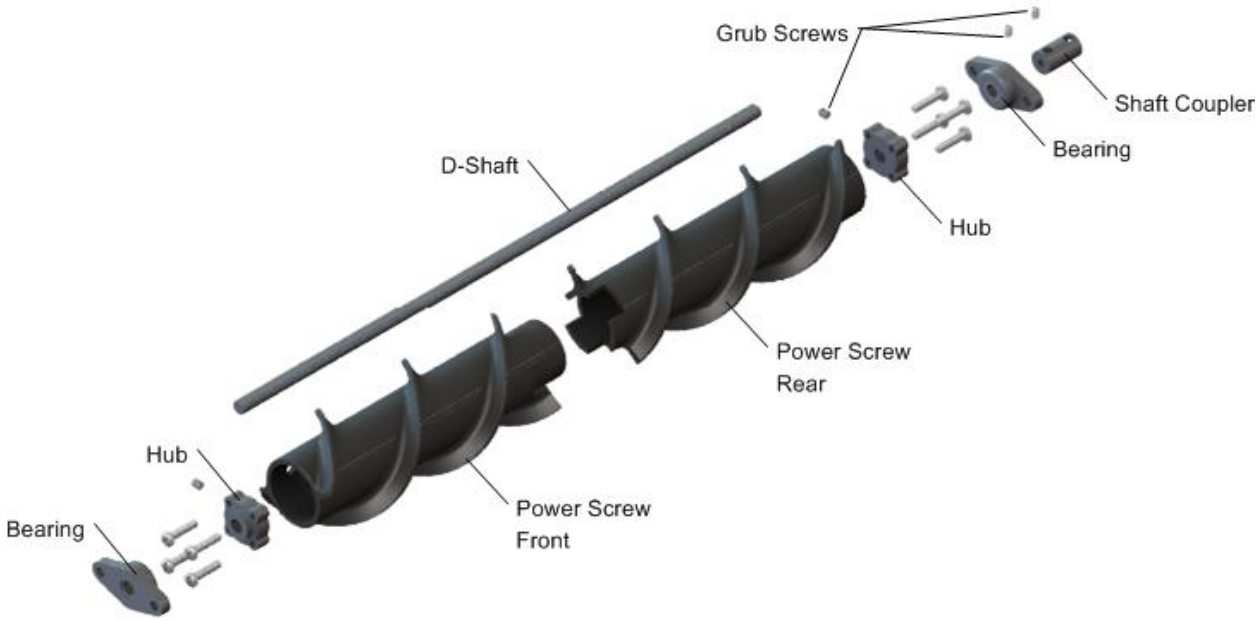


Figure 105: Exploded View of Power Screw Assembly

As can be seen from the above image, a ¼" diameter x 12" long steel D-shaft will run through the middle of the screws. An aluminum hub on each end will attach the D-shaft to the power screws. Four 6-32 screws will screw the hub into a flange inside of the screws. These hubs then have a grub screw that go through it and screw into the flat part of the D-shaft. To support the shaft, an aluminum mounted bronze bearing is being used on each end. The bearings then screw into 3D-printed supports with 8-32 screws which are not shown. The D-shaft then attaches to the motor shafts via a coupler. This coupler uses two grub screws similar to the hubs. Finally, to make sure everything is held securely, Loctite 680 Metal Retaining Compound will be used.

Requirements	Features	Verification/Testing
*The rover must travel at least 20 feet once it has landed.	3D printed power screws will be used to move the rover.	The 3D printed screws will be tested on several terrains once delivered. They will also be tested to insure they can sustain stresses from landing.

Parachute Cam

This system is one of the highlights of the rover as it is all been custom made. The purpose of the parachute cam is to detach the parachute from the rover to prevent from having to drag the parachute around (leading to potential snags), after the rover lands. The 3D model can be seen in Figure 106. The reason that the Parachute Cam was placed near the rear is so that the rover can fall with the camera facing down due to the rover's weight distribution. As can be seen from the model below, the main cam was changed from PDR so that the piston could have support while being inactive.

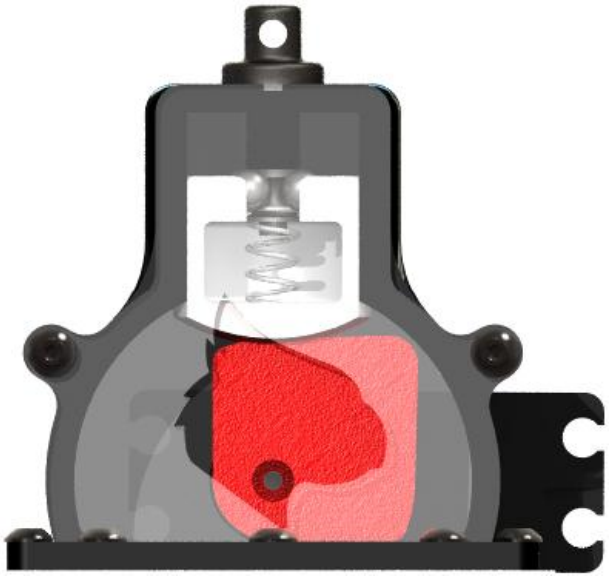


Figure 106: 3D Model of Parachute Cam

When the pressure sensor on the custom PCB determines that it has landed, it causes the BeagleBone to activate the servo that is attached. The servo is attached to a cam which holds the piston in place. The spring acts to push the piston downwards, and by rotating the cam 180 degrees, the spring is over powered and the piston is pushed upwards. By pushing the piston upwards, the four ball bearings will fall into the empty space beside the spring. The purpose of the ball bearings is to hold the pin as it has a grove for the bearing to fit into. With the ball bearings out of the way, the spring decompresses and ejects the pin. The pin has a hole to allow the parachute lines to go through. To prevent these components from coming out of the housing, a cover made out of clear acrylic will screw onto the front. To add to its custom uniqueness, the school's mascot will be cut into the cover.

All of the plastic components will be 3D printed and are currently awaiting delivery by the university's prototyping lab. The pins are machined out of 1018 Low Carbon Steel which has a yield strength of 54,000psi, so it will be able to sustain the force from opening the parachute without any problems. To insure that the plastic and the entire system as a whole can sustain the stresses from holding the entire payload, a gauge will be used to test how much force it can sustain before breaking.

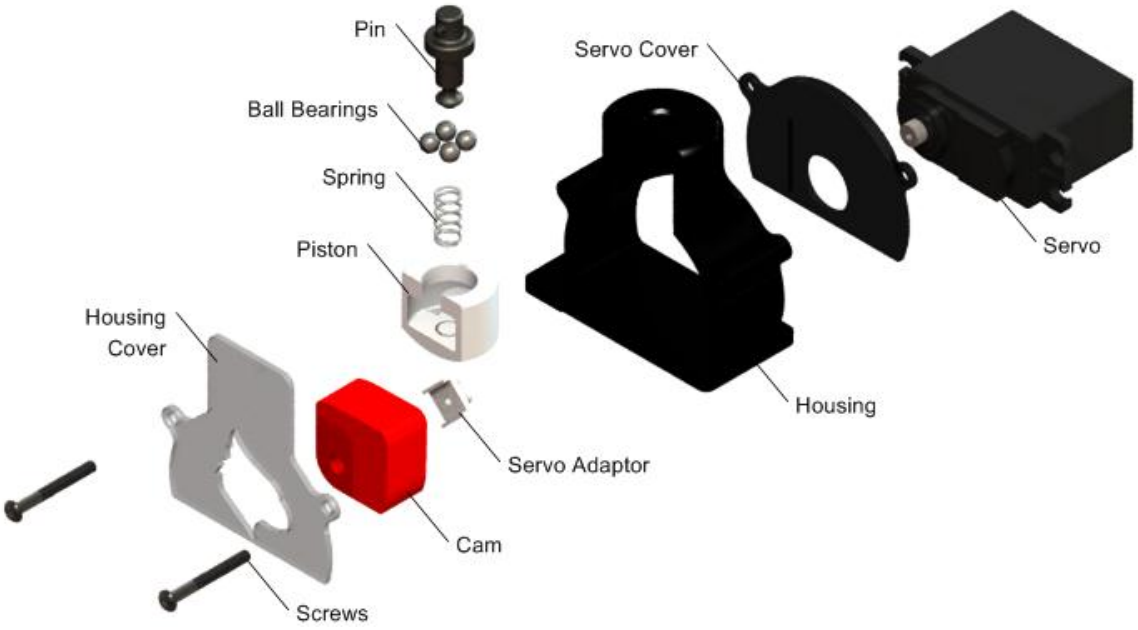


Figure 107: Exploded View of Parachute Cam

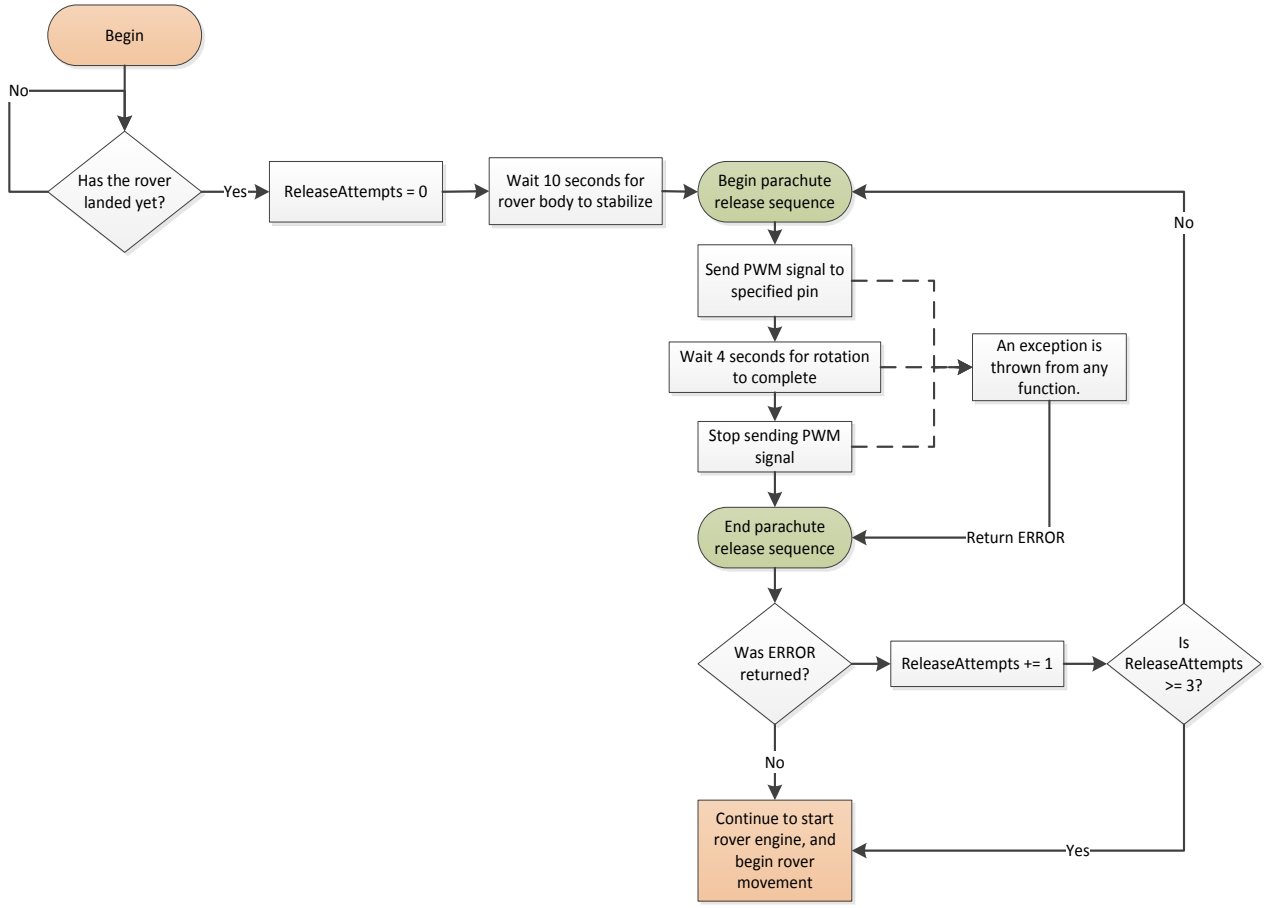


Figure 108: Parachute release algorithm

The parachute release algorithm first waits for the landing event to occur, to prevent detaching the parachute midair or before launch. Once the payload has landed, it will wait a period of 10 seconds before proceeding further. This is done to increase the probability that the body of the rover is physically stable (IE not rolling down a slope). After the rover has waited 10 seconds, the parachute release sequence begins.

The parachute release sequence simply consists of sending a PWM signal with a specified duty cycle (85 was used for testing) to a designated pin for a given time period (4 seconds was used during testing) that is attached to the parachute release servo. This action will cause the servo to rotate 180 degrees, and thus release the parachute from the rover body. Finally, the payload will stop sending PWM signals to the servo. If during this process, any software exceptions occur, the program will return an ERROR status. This status will tell the calling function that an exception occurred.

If an error occurred, the calling function will restart the servo rotation code, up to a maximum of three tries. If no errors are returned from the parachute release sequence, or the number of failed attempts is 3 or more, the rover will continue, and attempt to move

forward. When the parachute fails to release three times consecutively, it is assumed a software or hardware error has occurred, and that it is best to attempt to move forward, even if the parachute is still attached.

Test Results

The team has verified that the servo rotation portion of the parachute release system is operational. The team wrote a program that successfully rotates the servo 180 degrees clockwise, which fulfills the primary requirement of this system. The team has also verified that the parachute release device will properly release the parachute from the rover body. The next step for the team is to integrate the servo into its housing to test and verify that rotating the servo will properly trigger the parachute release action.

Requirements	Features	Verification/Testing
*The rover must successfully separate itself from the parachute once landed.	The Parachute Cam system is specifically designed to detach the rover from parachute by ejecting the pin holding the parachute lines.	The system will be tested to insure it can sustain the forces from opening the parachute. It will also be tested to make sure the lines are ejected away from the rover. The previous version was able to shoot the pin over 4 feet away.

References

Kenji Nagaoka, Masatsugu Otsuki, Takashi Kubota and Satoshi Tanaka. *Terramechanics-based Propulsive Characteristics of Mobile Robot Driven by Archimedean Screw Mechanism on Soft Soil*. Taipei, Taiwan: IEEE, 2010. 4946-4951. Web. 3 Jan. 2014.

PAYLOAD CONCEPT FEATURES AND DEFINITION

Creativity, Uniqueness, and Significance

The hazard detection payload is unique in the competition as it is the being integrated onto a rover. The significance of why a rover was chosen is because a hazard detection system could be a crucial system of any future rovers sent to other planets. A rover also expands the capabilities of the hazard detection system since the rover can drive once it has landed, thus continuing its mission but on the ground. With further work, the rover could potentially drive to the location it identified as a hazard to further investigate. The rover's design allows it to go over many terrains due to its creative use of power screws for movement. By using a rover, the team hopes to engage the community in space exploration. Also due to the many of the rover's components being 3D printed, the team hopes to spread to the public, the significance of using this new technology. Through the creative use a rover, the team is able to have a unique payload to differentiate from the rest of the teams in the competition.

Besides being a creative method of engaging the public, the hazard detection system performs a complex task which is currently the subject of several scientific projects. The reason is that object detection/recognition is a very important topic that could allow the automation of many tasks. By using OpenCV and an off-the-shelf webcam, the team is able to reduce the costs of the detection system which would allow others to repeat or further expand the system from their own computers. To move the system away from the computer, the team is using the BeagleBone Black which is unique platform since it is a Linux microprocessor which is much powerful than a Raspberry Pi or Arduino. The BeagleBone is significant to the payload as it is capable of running several complex tasks and is compatible with many systems already available. One such system is the GPS/GPRS cape the team is using to obtain and transmit data. The use of SMS to transmit data is significant as it allows the payload to send data to anyone who has a modern phone as well as to any enabled webserver. Overall, this payload achieves many complex tasks that could be useful for future planetary missions, and is also able to engage the public due to the unique rover design which is sure to attract attention.

Level of Challenge

The payload this year requires interdisciplinary work between computer, electrical, and mechanical engineering students. Due to this, the main challenge the team faces is having good communication skills between all majors to keep development running smoothly as there are many systems aboard the rover that have to co-operate to make this payload a success. Good communication skills are not just required for this project but in the real world, which therefore makes this project a good learning experience.

The main technical challenge the team faces is coding the software package so that all systems operate as intended. This requires the hazard detection algorithms to be as accurate as possible. Fortunately, image processing is a topic covered at the

undergraduate level. The second obstacle will be transmitting the data to our ground station via SMS. Since last year's payload used SMS to transmit data via a cell phone, the coding for this payload will be easier thanks to the amount of documentation available. Since the payload is getting centralized around a rover concept, the rover must be able to secure all the components and survive landing independently of the rocket. Fortunately, the team has full control over the rover's design and is able to 3D print parts as necessary to insure that everything is structurally safe. Overall, this payload has several challenges that will need to be overcome to make it a success, but the level of difficulty is within the skills of the members on this team, due to the rigorous nature of the University of Louisville's engineering program.

PAYLOAD SCIENCE VALUE

Payload Objectives

The success of the recovery mission depends directly on the success of the scientific payload. The camera on the rover will contribute substantially to the success of the mission through visual recognition of hazards while the payload is in decent. The purpose of this payload will be to scan the terrain for potential landing hazards using a custom software package. The data from the hazard camera will have to be processed onboard and transmitted to a ground station in real-time. The hazard detection payload must meet the following objectives in Table 44 as set forth by the Statement of Work (SOW) to be considered a success. Requirements marked with an asterisk (*) are those set additionally by the team.

1. The payload shall incorporate a camera system that scans the surface during descent in order to detect potential landing hazards.
2. The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.
3. The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station.
4. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.
5. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.
6. The electronic tracking device shall be fully functional during the official flight at the competition launch site.
7. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.
8. *The rover must successfully release its parachute once landed.
9. *The rover must travel at least 20 feet once it has landed.
10. *The system should report any errors preventing full functionality.
11. *The system should wait until the launch phase of operation to perform in-flight activities.
12. *The system should send an acknowledgement of the launch event in real time to the web server.

Table 44: Payload Objectives

Payload Success Criteria

To be able to call the objectives mentioned above a success, the payload must meet a few criteria so that it can be called a success. Success of the mission includes: detecting apogee, recording local hazards, landing safely, and collecting/transmitting environmental data to a designated device. Explaining further on the mission success, we are testing unconventional locomotion methods on this rover, given a safe landing is

achieved. The vehicle is moved along by the thick “screws” that run the length of the rover. Success of locomotion for the rover would be an incremental qualifying procedure for this variety of movement. By meeting the criteria listed below, the payload will have met all the requirements in the Statement of Work.

1. The GPS coordinates sent to webserver must match the expected the location.
2. Each of the tested hazards must be able to be detected and identified correctly 90% of the time.
3. Data is sent to webserver correctly 90% of the time.
4. Rover is able to detach parachute and drive off safely for at least 20 feet.
5. All electronics must be operational after 1 hour with the same power supply.

Table 45: Payload Success Criteria

Experimental Logic, Approach, and Method of Investigation

Due to the nature of the hazard-detection payload, most of the experiments to be performed by the payload will be evaluated on a pass or fail basis. To verify that our software package is correctly registering and identifying a hazard, we will have to visually compare that the object identified in an image is the hazard that we were looking for. The visual detection of the payload will be based algorithmically on OpenCV framework. The image processing program will be tested to insure that it can identify any of the hazards we tell it to. This will happen by comparing filtered and unfiltered images. These images will then give the image processing part of the payload a pass or fail grade.

The experimentation of the rover will be to traverse the given landscape with the unconventional transportation. The approach to the experiment will be in predicting distance travelled and efficiency of travel with the technology being qualified on the rover. Our method of investigation pertaining to the locomotion will be to design the optimal algorithm for traversing the given terrain. Tests will be conducted on several terrains to insure that using power screws is a viable method of locomotion. Similar to the image processing, a pass or fail will be given to the system.

The experimental logic behind the pressure sensor will be to insure that it can accurately read different pressure values. These values are of significance as it tells the payload what altitude it is at. This is important not only for payload events, such as activating the parachute cam, but it provides a method of analyzing the rover’s parachute. This will be good in determining if it was sized correctly. The approach that will be taken is to have several launches with the pressure sensor on a rocket, and then comparing these values to an altimeter. If the values are similar than it will be given a pass.

Tests and Measurement

To insure that the Hazard Detection Payload works, the team will conduct several experiments that will test each of the payload’s critical components. Table 46 shows the

tests the team currently plans to conduct as well as what measurements would qualify it a success. These tests are based off of the success criteria mentioned earlier.

Tests	Success Qualification
Run motors at full throttle until they stop	ESCs and motors do not overheat or fail and must run for at least 1 hour
Run BeagleBone and attached peripherals until LiPo loses power.	Electronics are still powered after an hour of operation
Gather & Send GPS data to webserver	GPS coordinates must be received and match expected location by using Google Maps without much latency
Run image processing software	Each of the tested hazards are able to be detected and identified correctly 90% of the time
Run image processing software and transmit data to webserver	Data is received correctly 90% of the time with no more than 10% packet loss
Run image processing software at different altitudes	Software is able to identify hazards 90% of the time at altitudes yet to be determined
Drop rover with parachute attached from at least 50 feet.	Accelerometer is able to detect landing, rover doesn't land upside down, and no components are damaged or detached
Drive rover over several different terrains	Must go at least 20 feet without problems
Activate Marker Cam to release the parachute and drive rover	Rover doesn't get tangled with parachute
Launch the pressure sensor in a rocket multiple times.	The values obtained via the pressure sensor must be similar to those obtained via an altimeter.
Rocket Launch Tests	All systems operate correctly and rover survives landing

Table 46: Hazard Detection Payload Tests

Variables

Since the rover will be ejected from the fairing in the air, there are many variables that could affect this payload. The main variable that could affect this payload is weather conditions. The reason is that high winds could cause the rover to spin on descent which could blur the images the camera captures. This could cause the software programs to misidentify a hazard. A second variable will be the different shapes and sizes of the hazards that the software will be trying to identify. For example, a hazard we will scan for is a crowd which can be in any shape or color. The next variable that could affect the payload is the data that the BeagleBone is handling. If the BeagleBone captures an image which takes longer to process for hazards, the transmission to the ground station would be delayed. The next variable that this payload will experience is altitude. At higher

altitudes, the camera may have a harder time discerning shapes which could cause hazard misidentifications. The final variable that will greatly affect the rover is the terrain, as the power screws might react differently. To fight against these variables, the team will have to design several experiments to test how much the payload is affected and attempt to find a solution.

Controls

To test the functionality of the hazard detection payload, the team has some options it can use as controls. The main control will be at what altitude the rover is deployed from the fairing. The team will attempt to deploy the rover at several altitudes to see when software is able to detect a hazard. After an acceptable altitude has been identified, this will become a control point for the rover. A second control the team has is what hazards the software will be looking for. By narrowing it down to a few hazards, the system resources will be freed up, thus increasing performance. A third control the team has is how the data is encrypted when sending it to the ground station. By choosing an encryption method, the latency in data transmission may be decreased. A final control point is the design of the rover. This will allow the camera to be orientated in the best orientation possible so that it can better detect hazards.

Relevance of Expected Data

The data that is collected from the hazard detection payload is very significant as object recognition via images is a topic that is of great importance. By having a successful payload, the team will be able to demonstrate a possibly cheaper method of achieving this. By improving upon the information obtained from the team's payload, this system could be used by others to detect terrain hazards for other rovers sent to other planetary bodies. By doing so the best landing zone could be identified, thus potentially improving the mission's success.

Accuracy/Error Analysis

Due to the software for this payload being built from scratch, the accuracy of the components being using will have to be done by visual inspection. The team will have to compare the images taken from the webcam with the processed data to insure that the software package was able to correctly identify a hazard. Based upon this, we will be able to determine how accurate the system is and make modifications to eliminate any errors. Data transmission accuracy will also be done with visual inspection by comparing how many data packets were sent to how many were received, as well as checking if any of the data is corrupt.

Fortunately, a few of the components we plan on using contain datasheets which allow us to check how accurate they are. The table below summarizes the accuracy of these components for which there is data available. The accuracy for other components will be further investigated and added to this table in future reports.

Components	Accuracy Description
Telit GE864 – GPS Receiver	GPS is accurate to less than 2.5 meters when it's between -40°C and 80°C. Sensitive up to -163dBm on 48 channels.
BMP180 Pressure Sensor	The pressure is accurate from ±0.12hPa and its resolution is 0.01hPa.

Table 47: Component Accuracy Description

SAFETY AND ENVIRONMENT (PAYLOAD)

Safety Officer

The safety officer for the University of Louisville team is Emily. She is responsible for overseeing the actions of the rocketry team, making sure that all applicable FAA laws are observed, and ensuring the general safety and well-being of both the team and the public.

Environmental Concerns

The only environmental concern from this payload is a potential fire. This could be caused by the failure of one our LiPo batteries. As mentioned in Table 48, all personnel will be asked to stand away, and the range safety officer will immediately be contacted. If the fire cannot be contained immediately, local authorities will be contacted about the situation. Other than a fire, this payload poses no foreseeable environmental concerns.

On the other hand, the environmental concerns towards the payload could be slightly problematic. The main concern is loss of communication data due to altitude or being in locations where there is no network signal. This could result in partial mission failure due to loss of real-time data transmission. The payload will be tested several times at different altitudes to insure it is not a problem and network maps will be consulted to insure signal is available at all launch locations. Another concern for the payload is drift due to the wind once it has been deployed from the fairing. If the payload drifts for too long it could go into areas without network coverage. Besides losing connectivity, the payload could drift past the launch field into private property which could make retrieval a problem. The payload's parachute will be sized to reduce the amount of drift while still making sure the payload is able to survive the landing impact.

Risk Assessment

Table 48 shows the current payload risk assessment table for the hazard detection payload. The risk matrix is similar to the one described for the vehicle. A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, damage to the rocket and/or damage to equipment. A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. Material Safety Data Sheets for payload components can be found in the Appendix.

Hazard Detection Payload Risk Assessment						
Hazard	**Cause(s) of Hazard**	**Hazard Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
GPS/GPRS cape is not functional	1. Programming error 2. Electrical issues (battery failure, etc) 3. Physical defect (device is physically compromised during launch)	Results of hazard detection are not transmitted to the ground station and web server.	1	1. 4 2. 4 3. 5 Overall: 4	Moderate	All: The hardware initialization failure program that runs on device startup will tell the team if the GPS/GPRS unit is functional when it is on the launch pad. Section 1: An entry is present on the pre-launch checklist to verify the BeagleBone Black's battery is charged prior to launch.
Hazard detection camera is not functional	1. Programming error causes a crash of the camera code. 2. Electrical error in the camera subsystem (power outage, connection problem) 3. Hazard scanning performance is too slow for the required time frame.	Inability to use the camera would result in mission failure as no hazard data would be collected.	1	1. 3 2. 3 3. 4 Overall: 3	Moderate	1., 2.The hardware initialization failure program that runs on device startup will tell the team if the camera unit is functional when it is on the launch pad. 3. Image processing performance will be tested to verify that hazards can be scanned for in the required time frame, on the required hardware.
Data transmission from the GPRS unit is not functional	1. Poor network reception 2. Physical malfunction of the GPRS transmission device 3. The GPS or GPRS antenna is not properly secured to the BeagleBone Black. 4. A programming error causes the GPRS unit not to transmit data.	Data transmission failure would result in the ground station not receiving or recording hazard detection, flight event, or GPS data from the rocket payload. This would result in a mission failure.	1	1. 3 2. 5 3. 4 4. 4 Overall: 4	Moderate	1. The team has verified, via T-Mobile's online coverage map, that the launch field at the Bonneville Salt Flats has wireless coverage. 2. An entry has been added to the pre-launch checklist to send a test SMS message with the GPRS unit to a cellular phone. This will verify that no physical defects are preventing the GPRS unit from functioning prior to launch. 3. Entries have been added to the team's pre-launch procedures checklist to verify that the GPS and GPRS antennae are screwed in securely, and held in place with electrical tape. 4. The GPRS unit has been (and will continue to be) tested to verify that the SMS-sending code functions without error.
Ground station does	1. The ground station is not turned on when	Failure of the ground station to receive data from	1	1. 4 2. 4	Moderate	1. An item has been added to the team's pre-launch checklist to verify that the

not receive data from BeagleBone Black	the data is transmitted 2. The ground station does not have network reception when the data is transmitted	the payload would result in not recording hazard detection, flight event, or GPS data from the rocket payload. Such an error would constitute a complete mission failure.		Overall: 4		ground station is: powered on, fully charged, and properly receiving text messages before launch. 2. The team has verified, via T-Mobile's online coverage map, that the launch field at the Bonneville Salt Flats as well as other launch fields have wireless coverage.
Web server does not receive data from ground station	1. The web server host experiences internal issues when data is transmitted from the ground station [IE a DOS attack, scheduled or unscheduled maintenance]. 2. The FTP credentials used to upload to the web server are not correct.	Failure of the web server to receive data updates would result in failure to display launch events in real-time to web-based users, which is a partial mission failure.	2	1. 4 2. 5 Overall: 4	Low	1. The team will contact the web hosting service to ensure that access should be available during the launch time frame. A pre-launch checklist item has been added to verify that the above has been completed. 2. Added an entry to the team's pre-launch checklist to verify that FTP credentials in the ground station's source code match the current, valid credentials for the web server.
BeagleBone Black fails to boot up or run code.	1. The Linux OS could have been corrupted during previous use. 2. BeagleBone has suffered physical damage.	Inability to use the brain of the rover would result in complete mission failure.	1	1. 4 2. 4 Overall: 4	Moderate	All: The team has possession of 3 BeagleBone's which can be swapped out in case one fails. 1. The BeagleBone will be flashed with the latest Linux OS. 2. The BeagleBone will be inspected for any anomalies before each launch.
LiPo battery fails.	1. Battery catches fire due to low or high voltage. 2. Battery is punctured during transportation or landing.	Loss of battery will result in payload electronics to be unpowered. Depending on when the battery catches fire, the entire payload could be destroyed. Damage to people and property could occur.	1	1. 4 2. 4 Overall: 4	Moderate	1. The LiPo batteries will be recharged to safe levels after each use. The batteries will be stored in a special fire-retardant bag. 2. The LiPo batteries will be transported and stored away from parts that could puncture the batteries. The batteries will be inspected before and after each launch to insure they are not damaged.
Payload Components fall off during descent	1. Components are not attached securely onto electronics platform	All parts are crucial to payload performance so loss of any part would result in mission failure.	1	5	Low	1. All components will be inspected before flight to insure they are attached securely. Testing will be conducted to insure all parts can withstand parachute opening shock.

Components on Custom PCB do not work.	1. While soldering the components to the PCB, a short could have been made. 2. PCB layout could have been incorrect.	Depending on what parts fail on the custom PCB, failure could range from the BeagleBone not obtaining any power to not being able to control the motors and servo. This would result in mission failure.	1	1. 4 2. 4 Overall: 4	Moderate	1. Each component will be carefully soldered onto the PCB and it will be inspected after all parts have been placed to insure everything is soldered correctly. 2. The PCB layout will be inspected by all electrical engineering students on the team before sending out to be manufactured.
The ESCs become non-operational.	1. The ESCs could have their protection circuit disabled. 2. The input signal from the PWM circuit could have fried the microcontroller onboard the ESC	If the ESC fails to operate, the motors to run the rover would not move. This would result in partial mission failure	2	4	Low	1. The ESCs will be inspected to insure the voltage protection is enabled. 2. An oscilloscope will be used to analyze the signal generated by the PWM circuit.
The Voltage Regulation circuit for the BeagleBone fails to provide the correct amount of power.	1. The LM7805 IC could be damaged resulting in incorrect regulation. 2. While soldering the LM7805 onto the PCB, a short could be created on one of the pins.	The BeagleBone could get damaged from power overload which could cause the payload's brain to become non-operational. This would be a mission failure.	1	4	Moderate	All. The team has access to 3 BeagleBone boards in case one becomes non-operational. 1. The circuit will be tested to insure it correctly regulates voltage before getting hooked up to the BeagleBone 2. The PCB will be inspected to insure all pins are correctly soldered.
Parachute Cam system suffers structural failure upon deployment from fairing.	1. Stresses from opening the parachute exceed the ultimate strength of the components such as ABS housing or metal pin.	The rover will fall without parachute which will result in its destruction upon landing. Damage to property and people could also occur.	1	3	Moderate	1. The parachute cam system will be tested numerous time to insure that it withstand the impact stresses from opening the parachute upon deployment. If needed, the thickness or material of the system will be changed.
Parachute gets tangled with rover during descent.	1. Ejection from fairing could cause the parachute lines to get tangled with rover due to incorrect packing.	The rover could potentially descend without an active parachute leading to its destruction upon landing resulting in mission failure.	1	4	Moderate	1. The rover and its parachute will be carefully placed into the fairing to insure they do not get tangled. Tests will be conducted to insure tangling does not occur upon deployment.
The parachute cam system	1. The parachute, after being disconnected, is carried by	The rover cannot move forward, thus resulting in	3	1. 3 2. 4	Low	1. It is not possible for the team to control the weather conditions at the landing location. The team realizes this is a

does not clear the chute away from the body of the rover.	wind/gravity on top of/in front of the rover. 2. The parachute cam system does not supply sufficient force to lift the attached section of the parachute from the body of the rover.	failure of this mission objective.		Overall: 3		threat, and considers it an acceptable risk considering the time and cost of implementing a system to compensate for this problem. 2. The team has verified that the parachute release mechanism will eject the parachute lines from the body of the rover, barring mechanical failure or extraordinary environmental conditions.
The parachute release code executes before the rocket has launched, or during rocket ascent.	1. The code could read incorrect values from the pressure sensor that cause the servo to activate.	The parachute will be completely detached from the rover during descent, leading to probable destruction of the payload.	1	4	Moderate	1. An entry was added to the pre-launch checklist to verify that the servo is rotated in the proper position before launch. This check verifies that this problem did not occur before placement on the launch pad.
The landing event is not detected properly.	1. The pressure sensor physically/electrically/ programmatically fails.	The code that ejects the parachute from the rover and drives the rover forward is never executed, causing partial mission failure.	3	4	Low	1. The sensor will be tested multiple times to insure it does not give incorrect readings. When soldering the sensor to the PCB, each pin will be inspected to insure there is no short that could cause the sensor to fail.
The code that rotates the servo does not wait long enough for the servo to rotate	1. The library documentation for the used function (Python's time.sleep()) asserts that the requested wait time can be longer than requested, due to signals being caught in Python. 2. The sleep function that is used encounters an	The parachute is not cleared from the body of the rover, leading to a chance that the rover cannot move forward, causing partial mission failure.	3	4	Low	1. The team added a safety window of ~1-2 seconds to the amount of time the servo rotates. This will ensure that, if the servo does not rotate for the entire time length, the parachute will detach. 2. The sleep function will be tested multiple times to insure it works as intended.

	exception or has a bug, and exits early.					
The code to send the PWM signal to the servo pin fails.	1. The software library used to send PWM signals is not installed on the device. 2. The software library used to send PWM signals to the servo is not the correct version. 3. The software library used to send PWM signals to the servo contains an internal bug.	The parachute is not cleared from the body of the rover, leading to a chance that the rover cannot move forward, causing partial mission failure.	4	1. 4 2. 4 3. 5 Overall: 4	Low	1. Added an entry to the pre-launch checklist to ensure that the correct version of the PWM is installed and configured. 2. Added an entry to the pre-launch checklist to ensure that the correct version of the PWM is installed and configured. 3. The PWM code will be tested multiple times to insure there is no bug.
The code that waits for servo rotation to complete fails.	1. The library function used to wait for rotation to complete contains an internal bug. 2. Power loss is experienced.	The servo will continue to rotate to the end of its allowed range [because the PWM signal is never stopped], which could damage the servo's gears.	4	1. 5 2. 5 Overall: 5	Low	1. The code will be tested to insure there are no bugs present. 2. The cables will be inspected to insure they are plugged in securely.
An exception is encountered during execution of any function calls in the servo rotation code.	1. There are bugs in the programming language implementation used. 2. There are bugs in the PWM library used. 3. There is a programming error in the servo rotation code.	If the exception is thrown before the servo has been started, the servo will not rotate, which will lead to the parachute not being released, and possible non-critical mission failure.	3	1. 5 2. 5 3. 4 Overall: 5	Low	All: A try-catch block is placed around the entire servo rotation program. If any exceptions are encountered, the program will exit with a return code indicating an error has occurred. The process executing the servo rotation program will restart the servo rotation program up to 3 times if an error is encountered.
The parachute cam servo is rotated in the incorrect direction.	1. During assembly, a team member does not know which way the servo should be oriented to be sure that it rotates.	The servo cam will not rotate the correct direction. This will cause the parachute to not be released from the rover body.	3	3	Low	1. An entry has been added to the pre-launch checklist to verify that the parachute cam servo is oriented completely counter-clockwise. This is verifiable by visual inspection. The assembly will also be tested to ensure that the servo will rotate in the proper direction when used.

Pressure sensor data does not reflect actual pressure.	1. Physical/electrical defect in the sensor hardware 2. Holes to allow air to enter are not present in the pressure sensor bay.	Launch, apogee, and landing detection have a strong possibility of being either incorrectly detected, or not detected. Each case is dealt with separately below.	1	1. 4 2. 4 Overall: 4	Moderate	Thorough testing will be done during development to ensure the pressure sensor's readings are accurate. Also, an entry has been added to the pre-launch checklist to take a sample reading from the pressure sensor, to verify that it is accurate.
The determined baseline pressure is not accurate.	Weather changes over time render the baseline pressure determination inaccurate when the rocket launches.	An inaccurate baseline pressure estimation will lead to not accurately detecting the launch time. However, launch should still be detected, before or after launch actually occurs.	4	4	Low	An entry has been added to the pre-launch checklist to compare the pressure reading at time of payload initialization with time of launch, to verify the difference is not too large.
Apogee is not properly detected.	The observed time range is not large enough to detect apogee	Apogee is not detected: The system will continually loop, checking for apogee. Thus, image processing and rover driving steps will never run, constituting partial mission failure. Apogee is detected early: The apogee detection message will be sent at the wrong time, and image processing activities will start early, having no functional impact on payload performance. Apogee is detected late: The image processing step of flight is possibly missed completely, leading to partial mission failure. Landing detection and rover operations should still continue without issue.	2	5	Low	The time range over which the program will attempt to detect apogee will be made as large as possible, so that the odds of the rocket coasting for the entire time period is minimized.
Rocket launch is not	1. A temporary change in weather causes a	If rocket launch is not detected, image processing	2	1. 5 2. 4	Low	Mitigations have been added to ensure the detected baseline pressure is accurate.

properly detected	large pressure change, falsely triggering launch detection 2. The baseline pressure is not determined properly	and rover activities will never occur, constituting partial mission failure. If launch is determined early, it's possible that the rover will attempt to move forward inside its housing and release its parachute, causing destruction of the payload after descent. If rocket launch is determined late, it's possible that image processing activities will not occur during rocket descent, leading to partial mission failure.		Overall: 4		
SMS sending hardware is not functional	1. Physical/electrical/programmatic error in the SMS sending hardware	The launch, apogee, and landing detection events are not reported to the ground station, leading to partial non-essential mission failure.	2	4	6	Thorough testing will be done during development to rule out most preventable programming errors.
Rocket landing is not properly detected	1. At apogee, the rocket coasts (nearly) horizontally for an extended period of time 2. The rocket lands on unstable ground, which gives way after a period of time more than 10 seconds	The parachute will not release from the rover, and the rover will not move forward, causing partial mission failure. If landing is improperly detected while the rover is still inside the rocket body, the rocket's wheels would turn, possibly causing damage to the foam in the rover's housing. Also, the parachute would be released from the rover on the launch pad, causing almost certain destruction of the rover and payload after descent.	2	1. 4 2. 5 Overall: 4	6	The current rocket design is not able to handle unpredictable ground conditions at the landing site. The risk from this error has been deemed acceptable.

Table 48: Hazard Detection Payload Risk Assessment.

PAYLOAD CRITERIA

TESTING AND DESIGN OF PAYLOAD EXPERIMENT

The fairing can be divided into three main sections: the altimeter housing, payload housing, and fairing retention bay. Each section has its own primary role in ensuring the safe deployment and recovery of the specific payload. The main components that make up the fairing, including airframe and bulk plates, can be visualized as equally divided into separate halves.

Altimeter Housing

In order to save space within the confinements of the fairing, the team wanted to have a standalone altimeter within the fairing. This called for no separate altimeter bay. The team designed an altimeter housing, shown in Figure 109, that would be 3D printed from ABS plastic. The enclosure would incorporate a StratoLogger, a 9V battery, an acrylic glass face plate, and a screw switch that would be used to activate the altimeter.

Figure 109. Altimeter housing assembly.

The decision to use 3D printing of this component allowed for a unique design. The outer body of the housing has an outer diameter that matches the inner diameter of the coupler tubing where it sits in the fairing assembly. The housing hosts a body extrusion that will safely house a standard 9V battery. A vented lid was 3D printed separately. The lid is screwed in place and properly constrains the battery in place. Included in the 3D printed design are raised extrusions that will also be properly tapped to allow for the StratoLogger, screw switch, and the acrylic glass front plate to be securely mounted to the altimeter housing.

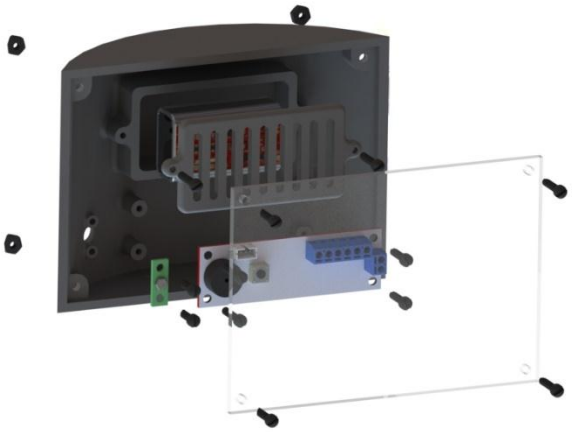


Figure 110. Exploded view of the altimeter housing.

Furthermore, there is a hole in the back of the altimeter housing which can be seen in more detail below in Figure 111. Once assembled, this hole will line up with a hole that will be drilled into the coupler tubing the altimeter housing rests in. This hole will allow access to the screw switch so that the altimeter can be armed on the launch pad.

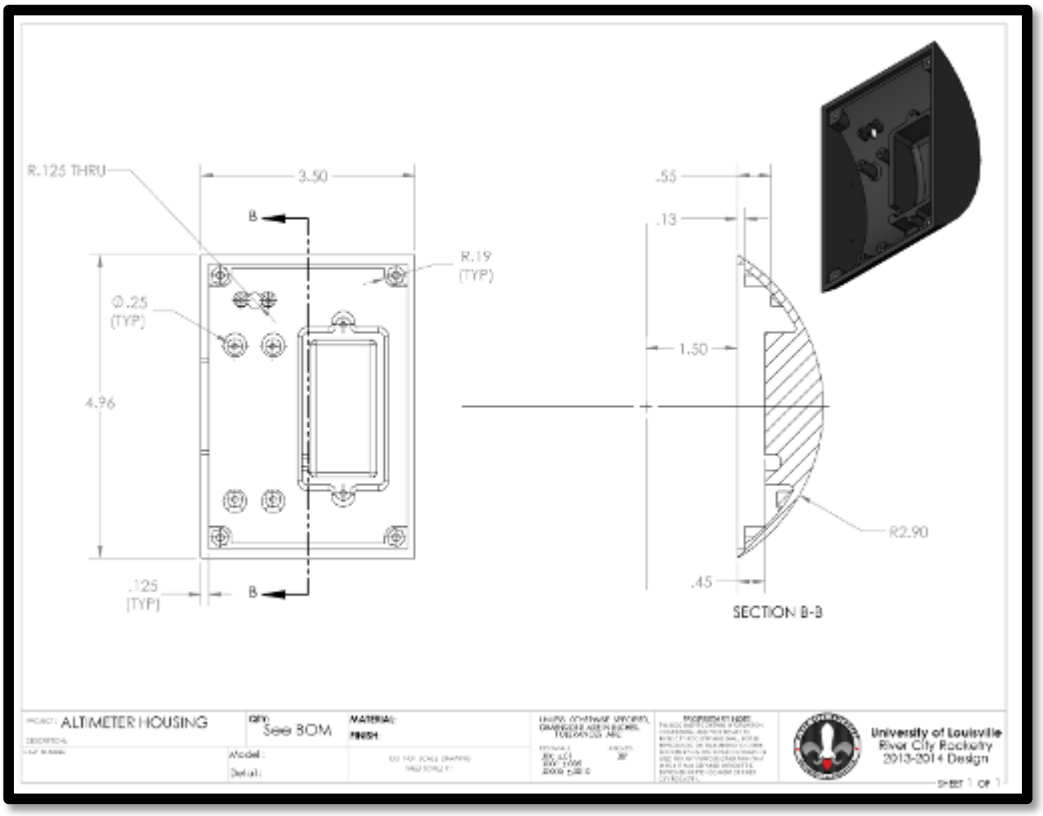


Figure 111. Altimeter housing basic dimensional drawing.

Utilizing information from StratoLogger's website, the port hole size for the altimeter housing was determined. Table 49 shows the information gathered and calculated from StratoLogger's website.

Avionics Bay			
Diameter (inches)	Length (inches)	Volume (in^3)	Single Port Hole Size (in)
1.6	6.0	12.06	0.032
2.1	6.0	20.78	0.048
3.0	8.0	56.55	0.113
3.0	12.0	84.82	0.17
3.9	8.0	95.57	0.202
3.9	12.0	143.35	0.302
5.5	12.0	285.10	N/A
7.5	12.0	530.14	N/A

Table 49. StratoLogger's volume to port hole size comparison.

In order to decide on the appropriate port hole size, the volume of the altimeter housing was calculated. This value was cross referenced against the information in Table 49 and the volume one step higher was chosen as guidance. A safety factor of 1.5 was chosen to influence the size of the final port hole size.

Altimeter Housing	
Volume (in^3)	78.91
Single Port Hole Size (in)	0.17
Safety Factor	1.5
Final Port Hole Size (in)	0.255

Table 50. Altimeter housing port hole analysis.

Table 50 shows the data used to determine the final port hole size for the altimeter housing. With the safety factor applied, it was determined that the ¼ inch hole used for the screw switch was adequate enough to act as a proper port hole for the StratoLogger.

Fairing Pyro Cap

The primary objective of the fairing is to safely deploy a specific payload at a predetermined altitude. The fairing is designed in such a way that the two halves of the fairing want to remain open in its equilibrium state. In order for the fairing to stay closed, thus encapsulating the payload, an aluminum pyro cap and shell will be used to securely

constrain the fairing shut. The shell that secures around the pyro cap is comprised of two sections, “Shell A” and “Shell B”. With the fairing being primarily completely symmetric in shape and split in halves, each bulkplate is a half-moon in shape. Each shell is securely mounted to its own half-moon bulkplate on one half of the fairing.

In the design of the pyro cap system, tolerances were a key item of concern. The shells had to be able to snuggly fit together, but could not be toleranced so tight that they would become stuck together if accidentally closed too tightly. In order to counteract this the radial dimension of the mating flange of Shell B was calculated and designed to a specific tolerance. Table 51 shows the maximum and minimum clearances for the fitment of Shell B into Shell A.

Shell B Clearance	
Maximum (in)	0.013
Minimum (in)	0.003

Table 51. Fitment clearances for Shell B into Shell A.

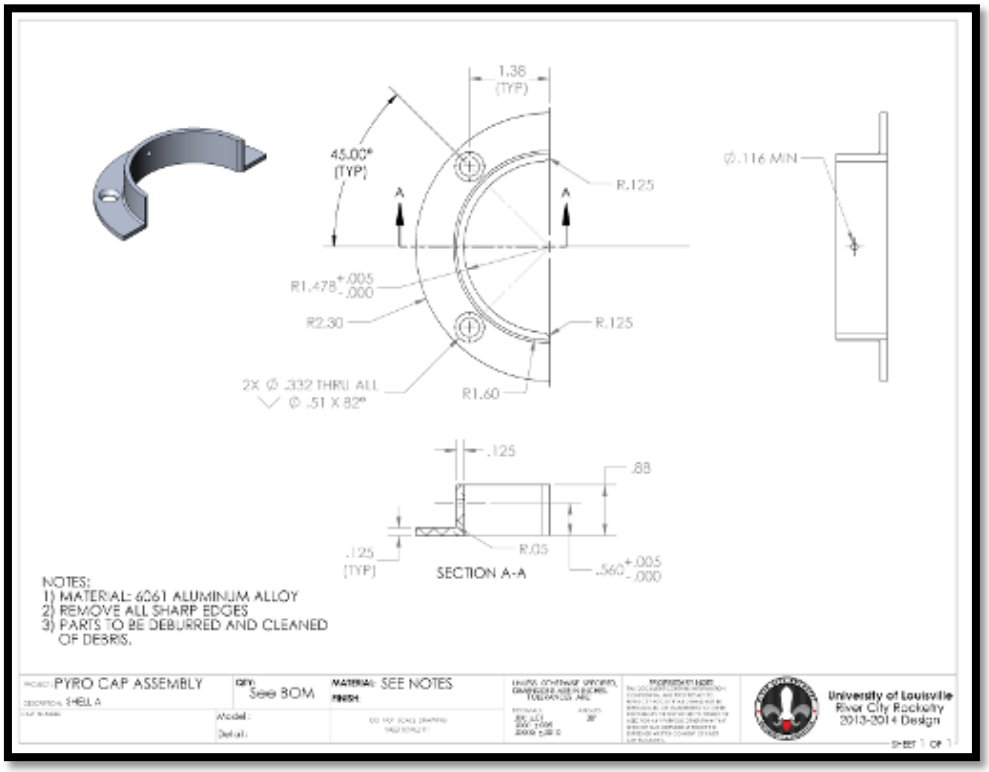


Figure 112. Detailed drawing of Shell A.

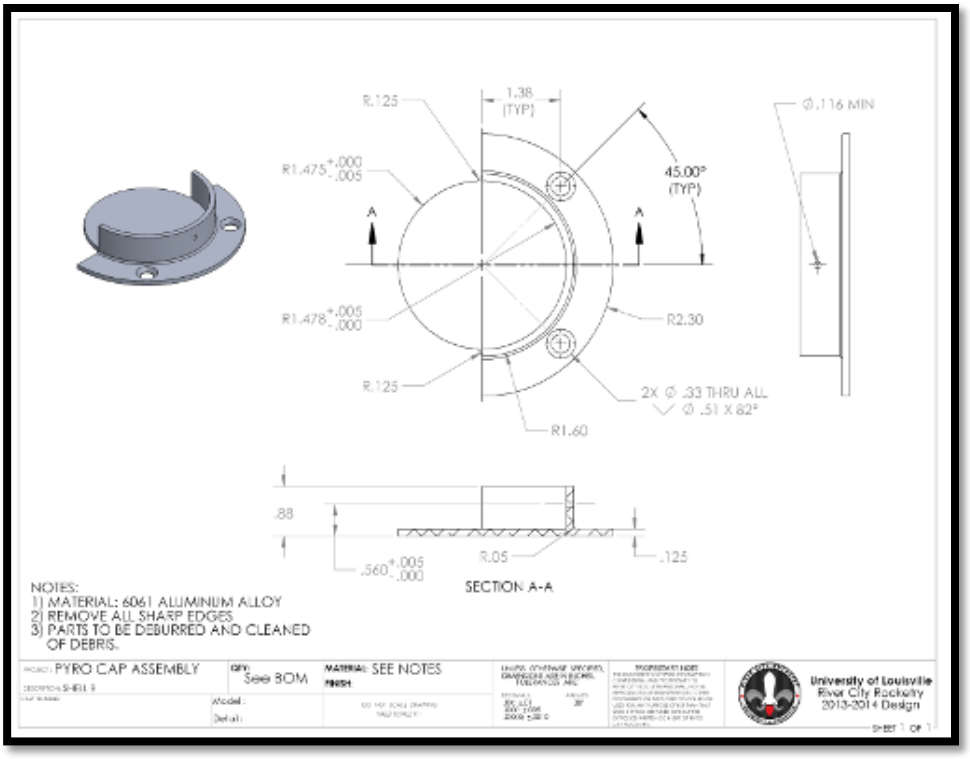


Figure 113. Detailed drawing of Shell B.

Similar to the tolerances going into the design of the two shell halves, the pyro cap went under the same rigorous precise design criteria to ensure a clearance fitment into the shells. Table 52 shows the clearance fitment for the pyro cap into the assembly.

Pyro Cap Clearance	
Maximum (in)	0.026
Minimum (in)	0.006

Table 52. Fitment clearances for the pyro cap into the shell components.

The pyro cap is designed to house two separate chambers for black powder charges. This is to ensure all rocket systems are fully redundant. To save space, the design called for the primary chamber to be a single bore. The secondary chamber is a ring that wraps around the central chamber. Figure 114 shows the overall design of the pyro cap.

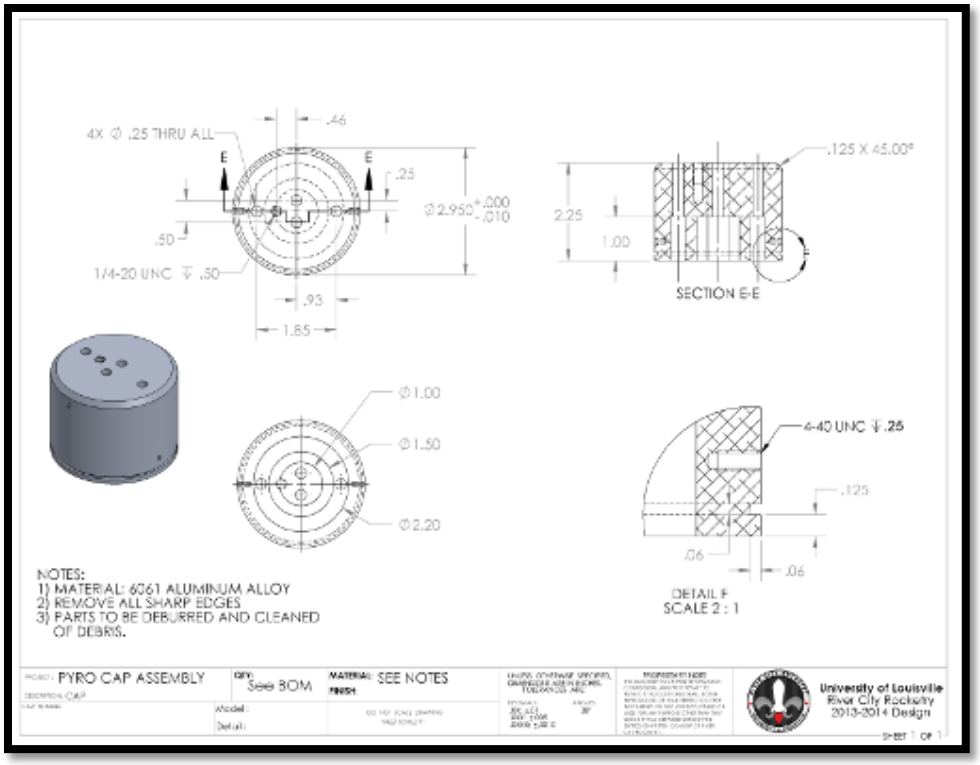


Figure 114. Detailed drawing of the pyro cap.

Black Powder Chambers (in)						
Center			Ring			Height
Diameter	Area	Volume	Thickness	Area	Volume	
1.00	0.79	0.79	0.35	1.16	1.16	1.00

Table 53. Black powder compartment dimensions.

Table 53 details the overall dimensions of the black powder chambers. To be fully redundant, the secondary chamber's volume was increased by one and a half. This was to ensure that in the event which the primary chamber's ignition fails to jettison the pyro cap, the secondary cap will fire with more overall pressure.

Various designs for the pyro cap were brought forth. The current design was chosen for various reasons. For one, having two chambers concentric about one another allowed for great space savings in an area of the rocket where space is limited. Secondly, by having the two chambers concentric about one another, when the black powder charges fire and

eject the cap, the cap will be jettisoned in the direction of the axis of the cap assembly. This will allow for a zero net torque on the system, and the force applied to the cap will be evenly distributed along the inner face of the chamber. Having the chambers next to each other could cause the cap to torque to one side and bind in the shell.

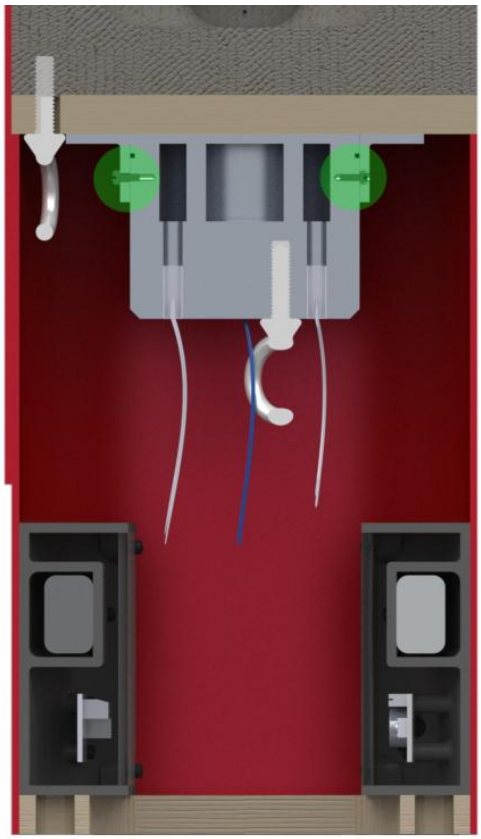


Figure 115. Section view of pyro cap assembly inside the fairing.

The pyro cap is secured into place by two 4-40 nylon screws, highlighted in Figure 115. A 1/10th inch thick silicone O-ring is placed within the O-ring groove on the outside of the pyro cap prior to assembly. A ¼ - 20 threaded eyebolt is to be epoxied into the top of the pyro cap. A section of 1/16th inch diameter nylon cord will be tied from the eyebolt on the pyro cap to the eyebolt mounted to the bulkplate to the side of the pyro cap assembly. This will ensure that when the pyro cap is jettisoned from the fairing that it will not free fall to the round where it could cause damage people or property.

A black charge will be housed within the cap. Two wires will be fed into the two inlet holes in the cap. Each wire will be connected to an electric match, thus allowing for redundancy in case one electric match fails. When the stratologger in the altimeter housing determines the fairing is at the proper altitude to eject the payload, it will fire the electric matches. When the cap's ejection charge fire, it will be jetisoned from the shell. The cap will still be connected to the main body of the fairing via a kevlar string to ensure it is not lost during flight.

Payload and Recovery Section

The final section of the fairing is self contained. This means that the section is completely seperated from the elements. The payload has to be constrained safely within the fairing. In order to do so the chosen method of constraint will be to have foam, that is specifically designed for aerospace applications, CNC'd to a precise geometric structure to securely house the payload.

Figure 116. View representation of one half of the fairing system.

Seperately, a section of foam will be CNC'd to house the parachute for the payload. Utilizing these foam inserts allows for a modular design of the rocket in the sense that any sized payload can be launched as long as its dimensions fit within the airframe of the rocket. Only a new foam piece would have to be machined. Furthermore, by housing the payload inside of the foam inserts, the payload will be allowed to easily "slip" out of the fairing once it begins to open.

General Plastics', of Tacoma, Washington, FR-7100 series multi-use core and modeling foam board has been chosen to be used in the teams fairing application. Not only is it offered in a variety of densities, it is a closed-cell foam material. This means the the foam will not absorb water or moisture. Therefore, there is little worry of the material warping due to environmental changes. The material is known for its durability and will suite the objective of the payload as requiered.

Specifically, General Plastics' FR-7110 closed-cell foam was chosen as the material of choice to house the rover and its recovery system. Table 54**Error! Reference source not found.** details the general material properties of the selected material.

General Plastics FR-7107 Rigid Polyurethan Foam	
Density (pcf)	7
Compressive Strength (psi)	182
Compressive Modulus (psi)	6759
Tensile Strength (psi)	235
Shear Strength (psi)	131
Shear Modulus (psi)	1606
Flexural Strength (psi)	193
Flexural Modulus (psi)	4303
Water Absorbtion (lbs/ft^2)	0.016

Table 54. General data information of FR-7107 foam material.

Due to the nature of high powered rocketry, the design, form, and function of the foam inserts had to be able to stand up to the rigerous requirements called for in this field of rocketry. In order to determine the proper material, analysis was completed to ensure that the maximum pressure the foam inserts would see in it's smallest cross-section would not exceed the structural limits of the selected foam.

Foam Material Selection Analysis				
Max Acceleration (ft/s^2)	Force on Rocket ($ft\text{-}lb/s^2$)	Pressure on Foam (psi)	Safety Factor	Required Compressive Strength (psi)
341	24722.5	49.97	3	149.91

Table 55. Analysis to determine proper foam material.

A safety factor of 3 was used in determining the appropriate foam material. The primary reasoning behind this, was due to the fact that while this material is not necessarily untested, the application for its use is. Table 55 lays out how the minimum required compressive strength was determined. The simulated maximum acceleration of the launch vehicle was used to determine the force on the rocket. From there, the force was applied tested against the smallest cross-sectional area of the foam inserts. This gave the team an estimated pressure on the foam at the weakest point. By applying the safety factor, the required compressive strength was determined. Comparing this data against the material properties of offered products from General Plastics, FR-7107 was determined to be the optimum foam material to be used for our application.

Requirements	Features	Verification
The payload shall safely contain the payload during flight	A specific foam material will encompass the payload and protect the payload from the stresses throughout flight.	Tests will be conducted with a subscale model that will simulate launch conditions. Analysis will be conducted of the foam and mock-payload post launch to determine what changes need to be made, if any.
At a predetermined altitude the fairing shall deploy the payload safely.	A two-piece aluminum cap and shell component containing a black powder charge holds the fairing together. Two extension springs create a torque which tries to pull the fairing apart. The onboard StratoLogger will fire the black powder charges, causing the pyro cap to eject, thus allowing the springs to pull the fairing open.	A subscale version of the fairing deployment system will be designed. Multiple tests will be conducted during subscale flights to ensure the system functions as planned.

PAYLOAD CONCEPT FEATURES AND DEFINITION

Creating a launch vehicle with real world applications was the primary objective going into the design of the payload recovery system. A faring was designed to allow a nonspecific payload to be encapsulated inside. The fairing functions by housing an allocated payload within itself. When the payload is ready for deployment, the fairing is opened and releases the payload. This method permits a payload of any size to reside within the faring as long as its dimensions are able to fit within the allowed space of the airframe. A broad spectrum of payload shapes and functions can be used without interfering with the recovery.

By this methodology, the team has developed a fairing system that has complete versatility. However, by adhering to this course of design, multiple challenges arise. Manufacturing such a design out of fiberglass poses an issue as wound fiberglass will warp when cut in half. This would cause the fairing's' shape to no longer mesh with that of the rest of the rocket. To alleviate this issue, prior to cutting the fiberglass in half, six holes will be drilled around the body of the fiberglass where bulkheads will later be installed.

Once the holes are drilled, the fiberglass will then be cut in half. A 12-ton press will then be used to slowly press the semi-circle birch bulkheads into place. Three wood screws will then be screwed into the holes previously drilled out. This will secure the shape of the fiberglass temporarily while high strength epoxy is applied to permanently constrain the bulkheads in place. This system of manufacturing the fairing will be tested during the subscale build and will prove reliable to the quality of the final product.

SCIENCE VALUE

The fairing has two primary objectives. Firstly, the fairing must securely house the payload and keep it safe throughout flight. The second objective is to successfully and safely deploy the payload at the predetermined altitude. If either of these objectives fail, the mission will fail.

To keep the payload safe, the team had to be certain their choice of foam would be able to withstand the stress of flight. The team sought guidance and opinions through various companies who design foam materials used specifically in aerospace applications. Exact documentation on how the foam will hold up would be near impossible to calculate do to the various unknown variables the launch vehicle could experience during flight. The foam will be rigorously tested both in subscale launches, and on the ground in the workshop.

In order to ensure a safe deployment of the payload, the action of the fairing must be smooth and precise. One point of failure could be the hinge that the fairing opens about. In order to ensure a smooth motion of the fairing opening, the team has implemented an aluminum hinge with 304 stainless steel pin. The main draw of the hinge are the polyacetal bushings. These bushings prevent metal-to-metal contact that could possibly induce undesirable friction.

SAFETY AND ENVIRONMENT (PAYLOAD)

Fairing Risk Assessment

The hazards outlined in Table 56 are risks that are related to the fairing. This includes potential risks during assembly, launch, recovery, and operation of the fairing.

Fairing Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sustainer does not eject from the rocket	1. Nylon shear pins do not fully shear. 2. Friction between sustainer and booster is too high.	Rocket will not achieve goal altitude. Rover will be unable to deploy. Rocket will still completely recover.	1	4	Moderate	1. Black powder charges have been designed to overcome the shear strength of the shear pins, allowing the rocket to separate easily. 2. The coupling between the two sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight.
Fairing gets tangled in parachute.	Improper packing of parachute.	Rover will not perform as intended.	2	3	Moderate	Special foam inserts are designed to house both the rover and the parachute in separate compartments. The foam inserts will keep the parachute shielded from the pinch point of the fairing when opened. The parachute is housed above the rover to ensure they do not become entangled during deployment.
Battery in altimeter housing dies.	1. Use past the normal life of the battery. 2. Extremely cold weather	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	2	5	Low	Batteries will be checked for sufficient charge during launch day preparations. If the launch is delayed and the batteries have been left on, batteries should be rechecked for a sufficient charge to power the systems.
E-match fails	1. E-match become dislodged. 2. Faulty e-match.	1,2. Ejection charges will not fire, preventing the rocket from splitting and the	1	5	Low	1. A pyro cap was specially designed and machined for this system to ensure secure connection of the e-matches to the black powder charges.

		rover being deployed.				2. The designed pyro cap allows for two separate black powder charges and e-matches. It is unlikely that the entire system will fail due to the redundancy.
Springs become dislodged.	Fairing does not completely open.	Rover will not deploy.	2	4	Low	Springs were selected with a high enough tension in mind to remain secure on the fairing.
Springs become fatigued.	Springs do not provide enough force to open fairing.	Rover will not deploy.	2	4	Low	Springs will be monitored for signs of fatigue and replaced as necessary. Springs are to be removed when not launching in order to prevent stretching.
Airframe becomes deformed	Airframe for fairing has a vertical cut through the entire airframe. Due to the nature of wound fiberglass, this could deform.	Rocket will become unstable and unsafe during flight.	1	5	Low	Airframe will have ribbed supports and internal components, such as bulk plates to support the structure.
Fairing does not separate from the sustainer	Friction between coupling and airframe is too high for pressurization from black power charge to overcome.	Rover will not deploy and will not be able to perform as intended.	1	4	Low	Coupling and airframe will be sanded to provide a smooth surface, allowing the two parts to easily separate. The springs that force the fairing apart were carefully selected to provide enough force to open the fairing upon separation, but not so much force that the rocket cannot separate.

Table 56: Fairing Risk Assessment

PROJECT PLAN

COMPREHENSIVE BUDGET/FUNDING PLAN

Vehicle Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
G12 Filament Von Karman Nose Cone	1	$122.55	$122.55
G12 Filament Airframe Tubing (1 ft)	9	$43.94	$395.46
G12 Filament Coupler Tubing (1 ft)	4	$55.76	$223.04
G12 Filament 75 mm Tubing (1 ft)	4	$19.48	$77.92
Acrylic Sheet (1/8" x 12" x 12")	4	$8.63	$34.52
1/4"-20 Hex Nut (Aluminum)	100	$0.06	$6.41
1/4"-20 Washer (Aluminum)	100	$0.07	$6.80
1/4"-20 U-Bolt (Aluminum)	4	$3.22	$12.88
1/4"-20 Threaded Rod (Aluminum) (3 ft)	2	$4.46	$8.92
D-Ring	4	$2.00	$8.00
4-40 x 1/2" Nylon Screws	100	$0.05	$5.34
Epoxy Clay	2	$11.95	$23.90
J-B Weld	10	$5.00	$50.00
Dog Barf Wadding (1 lb)	1	$5.00	$5.00
Cesaroni 75 mm-5G-WT M3100Motor	5	$269.96	$1,349.80
Cesaroni 75 mm-3G-WT L1720 Motor	7	$170.96	$1,196.72
Cesaroni 75 mm 5 Grain Hardware	1	$323.96	$323.96
Cesaroni 75 mm 3 Grain Hardware	1	$260.96	$260.96
Cesaroni Pro 75 mm Wrench	1	$30.29	$30.29
Aero Pack 75 mm Retainer Body	1	$30.00	$30.00
Aero Pack 75 mm Retainer Cap	1	$27.00	$27.00
6" Fiberglass Bulkplate	4	$8.55	$34.20
6" to 75 mm Fiberglass Centering Ring	3	$9.50	$28.50
6" Plywood Coupler Bulkplate	4	$5.90	$23.60
6" to 3.0" Plywood Centering Ring	3	$6.20	$18.60
Total			**$4,304.37**

Table 57. Vehicle budget.

Subscale Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
G12 Filament Von Karman Nose Cone	1	$46.01	$46.01
G12 Filament Airframe Tubing (1 ft)	7	$19.48	$136.36
G12 Filament Coupler Tubing (9 in)	4	$19.74	$78.96
G12 Filament 38 mm Tubing (1 ft)	4	$12.44	$49.76
G12 Filament 1/8" 1'x1' Fiberglass	3	$17.70	$53.10
Acrylic Sheet (1/8" x 12" x 12")	2	$8.63	$17.26
1/4"-20 Forged Eyebolt (Steel)	6	$2.89	$17.34
1/4"-20 Hex Nut (Aluminum)	100	$0.06	$6.41
1/4"-20 Washer (Aluminum)	100	$0.07	$6.80
1/4"-20 U-Bolt (Aluminum)	4	$3.12	$12.48
1/4"-20 Threaded Rod (Aluminum) (3 ft)	2	$4.46	$8.92
D-Ring	4	$2.00	$8.00
4-40 x 1/2" Nylon Screws	100	$0.05	$5.34
J-B Weld	10	$5.00	$50.00
Dog Barf Wadding (1 lb)	1	$5.00	$5.00
Cesaroni 38 mm-2G-IM H100 Motor	6	$28.76	$172.56
Cesaroni 38 mm-2G-WT H225 Motor	8	$29.66	$237.28
Cesaroni 38 mm 2 Grain Casing	2	$35.66	$71.32
Aero Pack 38 mm PML Motor Retainer	2	$29.00	$58.00
3" Fiberglass Bulkplate	4	$4.75	$19.00
3" to 38 mm Plywood Centering Ring	6	$2.63	$15.78
Total			**$1,075.68**

Table 58. Subscale budget.

Recovery Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
Garmin Astro 320 GPS Unit	3	$189.99	$569.97
Ripstop Nylon (62" x 36")	13	$9.50	$123.50
1/4" Dacron Rope (1 ft)	240	$0.36	$86.40
Perfect Flight StratoLogger	4	$85.55	$342.20
Goex FFFFA Black Powder (1lb)	1	$32.45	$32.45
Electric Matches	50	$1.25	$62.50
Lithium Ion Battery	2	$15.95	$31.90
Featherweight Raven	2	$155.00	$310.00
Featherweight Raven Power Perch	2	$35.00	$70.00
MissleWorks RRC3	2	$69.00	$138.00
Total			**$1,766.92**

Table 59. Recovery budget.

Fairing Payload Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
Bulkhead	3	$19.68	$59.04
Centering Ring	1	$6.89	$6.89
Bulkhead	1	$9.00	$9.00
Hinge	1	$27.87	$27.87
Square U-bolt	2	$15.76	$31.52
Hex Nut	8	$9.37	$74.96
Washer	4	$8.09	$32.36
Socket Cap Screw	6	$6.87	$41.22
Split Lock Washer	6	$2.71	$16.26
Hex Nut	6	$7.92	$47.52
Aluminum Stock 6"	1	$94.94	$94.94
Foam Insert	1	$300.00	$300.00
Pyro Cap	1	$200.00	$200.00
O-ring	1	$8.09	$8.09
Eye Bolt	1	$2.89	$2.89
Flat Head Socket	4	$2.71	$10.84
Extension Spring	2	$10.16	$20.32
Eye Bolt	1	$2.28	$2.28
Kevlar String	1	$23.73	$23.73
Heat Shrink Tubing	1	$7.03	$7.03
Total			**$1,016.76**

Table 60. Fairing payload budget.

Hazard Detection Payload Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
BeagleBone Black	2	$45.00	$90.00
ChipQuik 8cc Flux	1	$11.85	$11.85
Mini Solder Spool- 100gram	1	$5.95	$5.95
3-Axis ADXL345 Accelerometer Board	1	$19.95	$19.95
BeagleBoard ProtoCape Kit	1	$9.95	$9.95
Tacon 540XXL 2858 Brushless Motor 1200KV	2	$23.32	$46.64
Sky Lipo 1600mAh 14.8V 40C	2	$20.94	$41.88
XT60 Solid Bullet Connectors	1	$5.50	$5.50
Heat-shrinkable Tubing 04---black	1	$0.40	$0.40
LED Program Card For Brushless ESC	1	$8.99	$8.99

HobbyWing eZRun-35A Brushless ESC	2	$31.99	$63.98
0.125in to 0.25in Shaft Coupler	2	$4.99	$9.98
0.25in x 12in D-Shaft	2	$4.69	$9.38
0.25in x 0.77in Set Screw Hub	4	$4.99	$19.96
Aluminum Mounted Bearings	4	$7.97	$31.88
8-32, 5/8in Length Screws	1	$9.51	$9.51
8-32, 1/8in Height Nuts	1	$3.96	$3.96
4-40, 1/2in Length Screws	1	$1.63	$1.63
4-40, 3/32in Height HexNuts	1	$0.81	$0.81
5-40, 2in Length Screw	1	$13.60	$13.60
5-40, 7/64 Height LockNut	1	$4.43	$4.43
Loctite 680 Retaining Compound	1	$14.81	$14.81
Loctite 7649 Primer	1	$11.88	$11.88
8-32, 1/8in Height Nuts	1	$1.49	$1.49
6-32, 5/8in Length Screws	1	$2.50	$2.50
6-32, 3/32 Height Hex Nuts	1	$2.61	$2.61
SciGrip Plastic Cement	1	$5.71	$5.71
4-40, Male-Female Nylon Standoffs	1	$12.24	$12.24
4-40, 1/4in Length Nylon Screws	1	$5.23	$5.23
12in x 24in Black Acrylic Sheet	1	$18.80	$18.80
3in x 12in MultiPurpose 6061 Aluminum Rod	2	$51.97	$103.94
Logitech C920 HD Pro Webcam	1	$69.99	$69.99
T-Mobile Mobile Plan	30	$3.00	$90.00
Total			**$749.43**

Table 61. Hazard detection payload budget.

Travel Budget	
Expenditure	***Cost***
Vehicle Rental	$2,176.00
Gas	$1,730.65
Hotel	$2,000.00
Total	**$5,906.65**

Table 62. Travel budget.

Total Tentative Budget	
Vehicle	$4,304.37
Recovery	$1,766.92
Fairing Payload	$1,016.76
Hazard Detection Payload	$749.43
Subscale	$1,075.68
Educational Engagement	$1,500.00
Promotional Materials	$2,000.00
Travel Expenses	$5,906.65
Total	**$18,319.81**

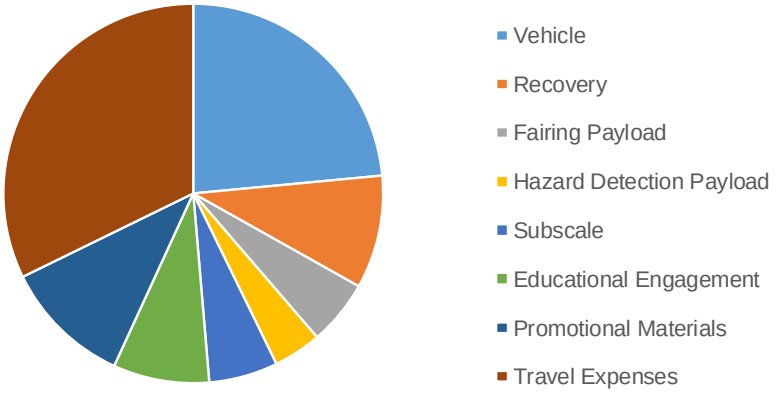


Figure 117. Total tentative budget.

COMMUNITY SUPPORT

Kickstarter: For the past two competition years, River City Rocketry launched a Kickstarter site to connect with the community and gain support. Kickstarter is a fundraising platform that allows creative projects to find support from people near and far. River City Rocketry offered various rewards to its supporters such as custom science boards, team t-shirts, and even advertisement or logo space on the rocket so that sponsors have a personal connection to the team and project. The site was a huge success for the team both years. By having a presence on Kickstarter, River City Rocketry has been able to share with the community their passion for science and rocketry.

Louisville Cardinal: The Louisville Cardinal is the independent student newspaper at the University of Louisville. The newspaper is widely read and respected by the students at the university. In years past, River City Rocketry took the opportunity to sit down for interviews with the Louisville Cardinal. This has allowed students from all over the university to see what the team is doing and the progress they have made.

Registered Student Organization: In the Spring of 2012, River City Rocketry has been a Registered Student Organization (RSO) at the University of Louisville. Since receiving RSO status, the team has been able to reach out to the Student Senate as well as several of the university's Student Councils to gain support and increase the knowledge of rocketry at UofL. The team has received very positive feedback and was elected last year's "Best New RSO".

TIMELINE

ID	Task Name
1	~~**Proposal Submission**~~
2	~~**Design**~~
3	~~Stability and Propulsion~~
4	~~Recovery Subsytem~~
5	~~Fairing Subsystem~~
6	~~Hazard Detection Payload~~
7	~~Team Teleconference~~
8	~~Team Web Presence Established~~
9	~~**Preliminary Design Review Submission**~~
10	~~Preliminary Design Review Presentation~~
11	**Testing**
12	Recovery Subsytem
13	Fairing Subsystem
14	Hazard Detection Payload
15	~~Sub Scale Testing~~
16	Mission Redesign After SubScale Testing
17	Motor Orders
18	**Critical Design Review Submission**
19	Critical Design Review Presentation
20	Data Analysis and Design Finalilization
21	**Manufacturing**
22	Recovery Subsytem
23	Hazard Detection Payload
24	Fairing Subsystem
25	Stability and Propulsion
26	Full Scale Flights and Final Revisions
27	Flight Rediness Review QA session
28	Test Flights 1 and 2
29	Third Test Flight
30	**Flight Rediness Review Submission**
31	Flight Rediness Review Presentation
32	**Systems Check and Revisions**
33	Travel to Salt Lake City
34	Flight Hardware and Safety Check
35	**Launch Day**
36	Return to Louisville
37	Launch Analysis and Data Compilation
38	**Post-Launch Assessment Review**

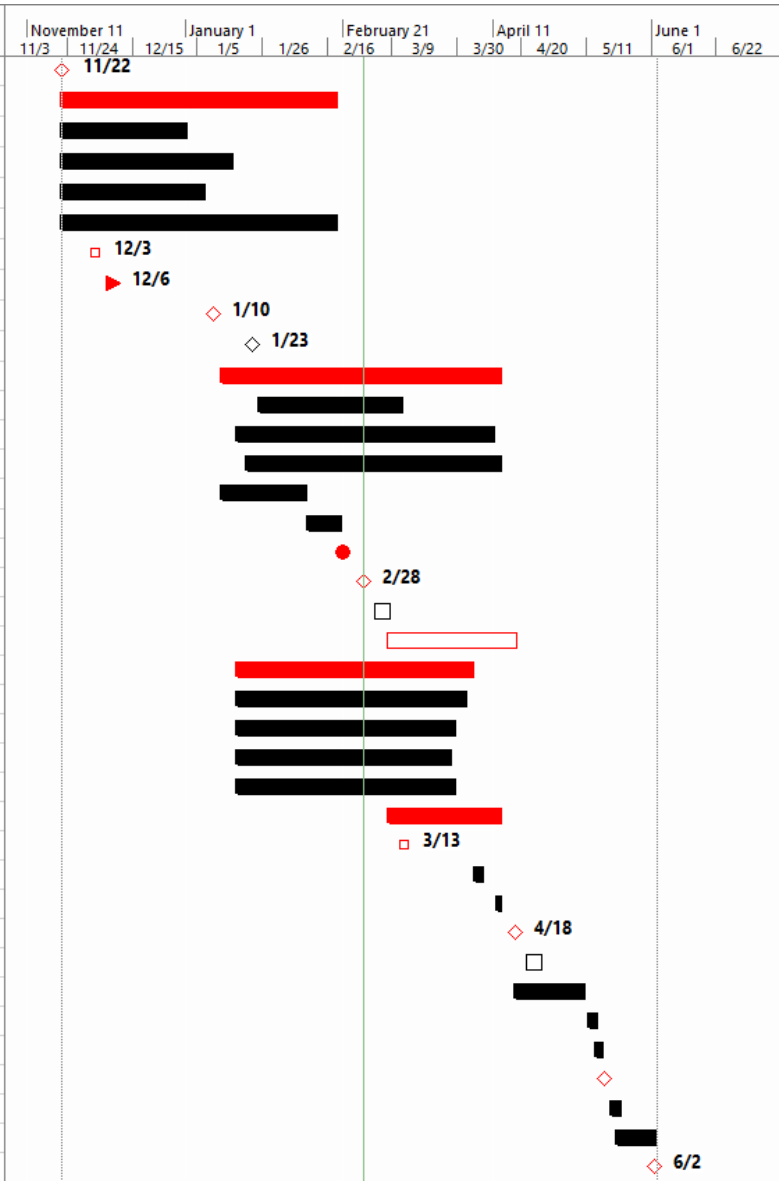


Table 63: Team timeline.

EDUCATIONAL ENGAGEMENT

In the past years, River City Rocketry benefited from the opportunity to reach out in our local community to bring STEM activities to students, parents, and educators. The team takes pride in the quality of events that we organize and orchestrate. With the new season, we have new exciting plans to further our educational presence in the community. The team acknowledges that the best way to reach the needs of our community is by receiving feedback on what is effective and what can be improved. We are always open for constructive criticism; so the team will always follow up with coordinators or educators whom we are working with to evaluate the success of our programs.

Figure 118. Elementary School Engagement

The newest addition to our curriculum this year includes a 6 week aerospace program at a local school, Shawnee Academy. Complete details of this new and exciting program are included below. In addition to this new program, we will continue to foster the relationships formed in the past years by connecting again with our most successful and valuable events. A complete list and description of planned events for the season are included below.

Engineering Exposition (E-Expo)

Since 2006, the JB Speed School of Engineering Student Council has hosted the largest student-run event on the University of Louisville's campus, the Engineering Exposition. The event is geared towards celebrating strides in engineering as well as getting the local youth interested in the field. During the event, the professional engineering societies on the University of Louisville's campus set up educational games and scientific demonstrations for the elementary and middle school aged participants.

Figure 119. Launching Paper Rockets at UofL

Last year, the team participated in the event and reached out to over 350 students with a customized water rocket competition. Teams of three elementary aged students were encouraged to use their creativity and problem solving skills to design their own unique water rocket. In preparation for the competition, members of the University of Louisville USLI team visited various schools to mentor the students and to educate them on the scientific reasoning behind why the activity works. On the day of the exposition, the team assisted the students in launching their water rockets using water pressure. Awards were given to teams in various categories in the competition. The event proved successful and the team's booth received high praise from the host. This year, the team plans to host the second annual water rocket competition during the 2014 Engineering Exposition with the goal of increasing participation in the event while continuing to provide an equally educational and creative hands-on rocket building experience for the students.

Boy Scouts and Cub Scouts

Over the course of the past year, the University of Louisville USLI team has worked with local Boy Scout and Cub Scout Troops to assist in the earning of the Space Exploration merit badge. The achievement of this badge is no easy feat. The Scouts are required to attend a day long program which includes space history lessons as well as building and launching small model rockets. Events will be planned throughout the year to encourage more of our local scouts to explore the realms of space and to earn their merit badge.

Engineering is Elementary

Last year, the team traveled to middle and elementary schools in the Louisville area to teach science, technology, engineering, and math (STEM) subjects while providing positive role models for the students. The team will continue to visit local schools to teach space history, space exploration, and rocketry to young students in addition to the core

STEM subjects. The Engineering Fundamentals Department at UofL will be providing the materials for the lessons and supporting these educational engagement activities.

Louisville Science Center

The University of Louisville is thrilled to be able to continue its partnership with the Louisville Science Center. The Science Center allows the team to be an active part of their educational environment. They also allow the team to periodically display our rocket so science center employees can discuss our project with visitors. Additionally, they have the ability to educate and entertain visitors with a paper rocket activity developed by the team. The Science Center has been extremely gracious in allowing the team to facilitate workshops for visitors as well as participation in Engineering Week at the Science Center.

The Academy at Shawnee High School

6 Day Program Curriculum

Day One: Mercury and Gemini Program History:

This lesson will go over selected missions of the Mercury and Gemini programs and their objectives. It will highlight several achievements of America such as Alan Shepard becoming the first American in space and John Glenn becoming the first American to orbit the Earth. The lesson will cover founding NASA and the beginnings of space exploration in the United States and U.S.S.R. Several core concepts will be taught throughout the lesson including:

- Rocket stability.
- Principles of aerodynamics.
- Newton's Laws.
- Basic rocket building techniques (Paper rocket activity).

Day Two: Apollo Program History:

This lesson will examine in detail the most monumental program in the history of manned spaceflight. The students will learn about the 17 Apollo missions: the fatal fire of Apollo 1, mankind's giant leap of Apollo 11, the "successful failure" of Apollo 13, and the rest of the historic moon landings. Core concepts taught during this lesson will be:

- Thrust-to-weight ratio.
- Improved rocket building techniques (Advanced paper rocket activity).

Day Three: Shuttle Program, ISS, and Curiosity Rover History:

This lesson will examine in detail the movement of NASA from making deep space missions to mastering low-earth-orbital techniques. The space shuttle will also be analyzed in terms of reusability. The International Space Station will follow with a look into what it takes to sustain life in low earth orbit. Finally, a brief look at the Curiosity Rover

mission will demonstrate how we land a probe on another planet. Students will have the opportunity to do the following:

- Understand the use of composites vs. metals in aerospace applications
- Design a payload that would fit inside the space shuttle cargo bay
- Design a space station with the fundamental elements for sustaining life
- See simulations of extra-terrestrial landing techniques for unmanned missions

Day Four: OpenRocket Simulation:

The class will have the opportunity to model a rocket using OpenRocket software. The model rocket will later be constructed and launched. This simulation software will allow students to see how flight trajectories and altitudes are accurately predicted. Concepts that will be reinforced are as follows:

- Software proficiency
- Understanding how math is applied through software solutions
- The importance of measurement accuracy
- Mass balance
- Stability margin acceptability

Day Five: Rocket Construction:

Each student will have the opportunity to construct and launch their own rocket. Rockets will be small Estes model rockets using black powder motors, and each student will be carefully supervised. The students will be led through a visual walkthrough of rocket assembly. The following concepts will be taught:

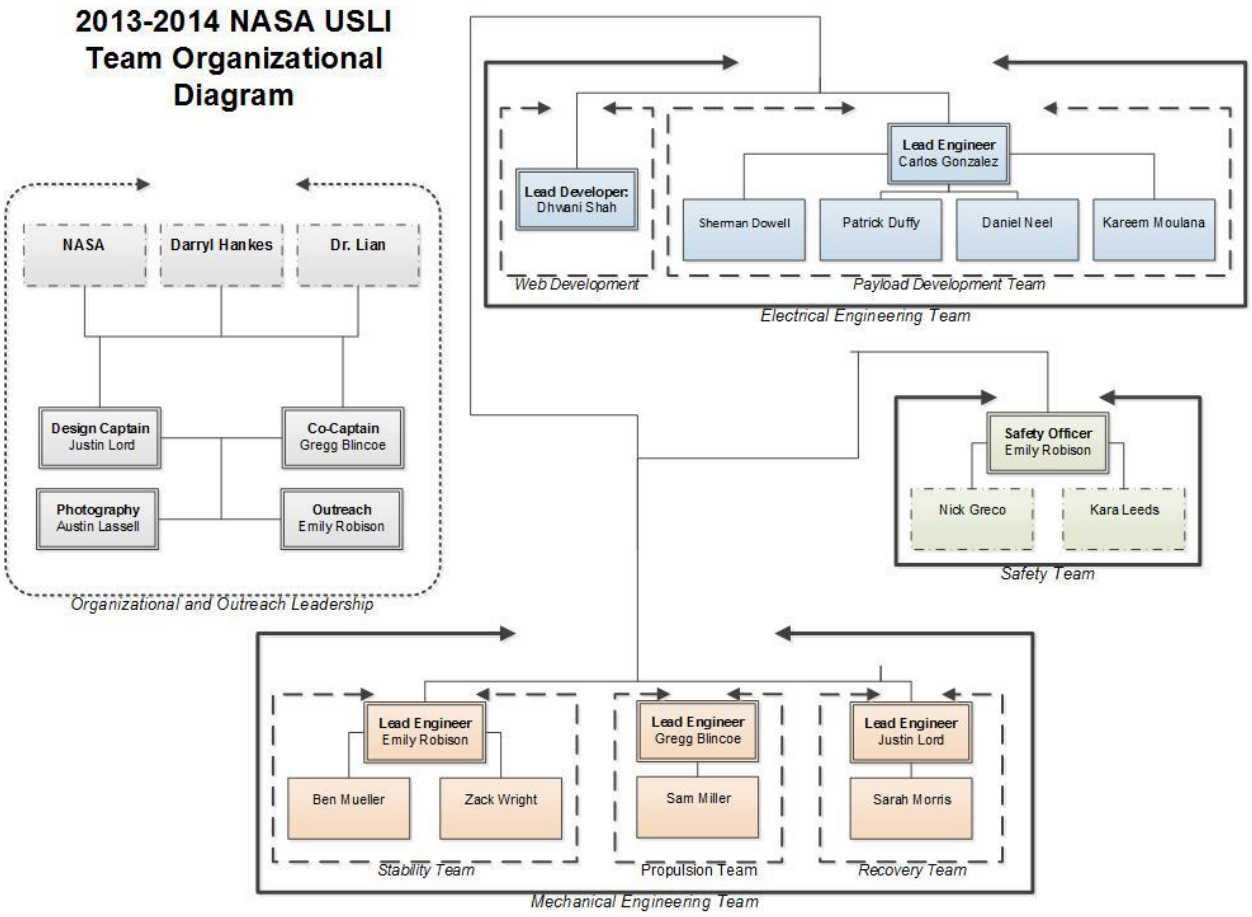
- Proper measurement
- Construction techniques
- Fin installation
- Launch lug mounting
- Shock cable and parachute organization

Day Six: Final Construction/Rocket Launch/Summation:

The students will be taught how to properly and safely setup launch pads. Any remaining construction work on the rockets will be completed during this session. The students will be taught how to pack parachutes, load motors, and develop a pre-launch checklist. Finally, the students will launch their rockets, and compare altitudes

Figure 120. Water rocket launch.

APPENDIX 1: SUPPLEMENTAL INFORMATION



APPENDIX 2: SAFETY DOCUMENTS

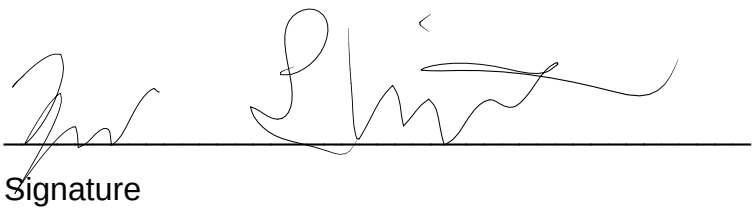
River City Rocketry

University of Louisville

Safety Compliance Form

By signing this form:

- I agree to comply with all safety rules and regulations set forth by the safety manual.
- I have read and am familiar with the entire document.
- I understand that it is my responsibility to remain up to date with the latest version of the safety manual.
- If I violate these regulations, I realize that I may not be able to participate in construction or launch activities.
- I will strive to follow these safety procedures and encourage safety throughout the team and at educational events.



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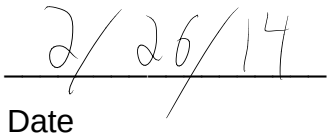

Date

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Signature

2-27-14

Date

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University of Louisville

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02/27/14

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Signature

2/24/2014

Date

River City Rocketry

University of Louisville

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2-26-14

Signature

Date

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University of Louisville
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Emily Robison _____ 2/24/2014 _____

Signature Date

River City Rocketry

University of Louisville

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C Gonzalez

Signature

2/24/14

Date

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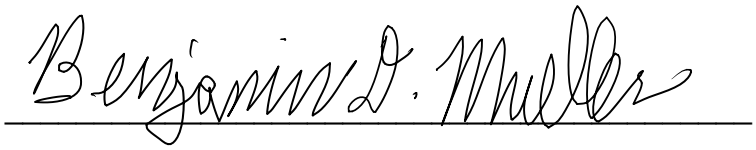

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Sherman Dowell 2/26/14

Signature Date

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University of Louisville
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Sam Miller

Signature

02/27/14

Date